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THE NEW JERSEY HIGH-LEVEL VIADUCT

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The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions

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A TIME STUDY OF TRAFFIC FLOW ON THE NEW JERSEY HIGH-LEVEL VIADUCT

Reported by **LAWRENCE S. TUTTLE**, Assistant Highway Economist, Division of Highway Transport, United States Bureau of Public Roads

Traffic Flows Freely on the Viaduct With a Considerable Saving in Time.

THE RECENTLY completed High-Level Viaduct between Newark and Jersey City in New Jersey has created wide interest because of the magnitude of the project and the engineering problems involved in its construction. Less publicity has been given the economic problems. Costing $5,200,000 per mile, it is one of the most intensive pieces of highway construction in the world. A careful preliminary investigation [1] indicated that of the various economies which would be effected by the construction of the express highway from Elizabeth to the Holland Tunnel, of which the viaduct is a part, the most important was the saving in travel time. This paper presents an estimate of the annual vehicle time saved by the viaduct under present traffic conditions, prepared from field studies of travel time on this express highway before and after the opening of the viaduct. The studies were made during 1932 and 1933 by the Division of Highway Transport, Bureau of Public Roads, with the cooperation of the New Jersey State Highway Commission. The field work was performed as an unemployment relief project in connection with the New Jersey State-wide traffic survey. No attempt has been made to value vehicle time saved in view of the general lack of agreement among engineers and economists on this subject, but the estimate has been so arranged that reasonable values for time saved for the several classes of vehicles may be easily applied to obtain the monetary value of the time saved.

OLD ROUTE BADLY CONGESTED

The viaduct completes the express highway from Elizabeth to the Holland Tunnel. This highway is one of the most heavily traveled in the country, as it is the principal approach from the south and west to New York City via the Holland Tunnel and the George Washington Bridge. It also serves a large volume of local traffic between Jersey City and Newark. Figure 1 shows the location of the viaduct and the previous routing of traffic. Before the viaduct was opened, traffic was routed east along Communipaw Avenue to West Side Park in Jersey City and then north to Tonnelle Circle, a distance of 4.2 miles.

Traffic congestion on this ground-level route often reached serious proportions. While the roadway provided at least two lanes in either direction at its narrowest point, interruptions to traffic and points of conflict were numerous. These consisted of frequent openings of the drawbridges across the Passaic and Hackensack Rivers, and traffic interference at numerous intersections, particularly at the east and west ends of the Communipaw Avenue section of the route, and also where Newark Avenue crosses near Tonnelle Circle.

Congestion at these three intersections was aggravated by heavy turning movements, requiring almost continuous police control. To a lesser degree, Tonnelle Circle was also a source of delay. In anticipation of construction of the viaduct the latter was not designed to accommodate a large volume of traffic, and before the completion of the viaduct an intricate system of police control was necessary to prevent complete tie-ups.

Traffic counts indicated that the total yearly traffic at the Hackensack River Bridge during 1932 was about 14,600,000 vehicles. Average week-day traffic throughout the year was approximately 37,000 vehicles, while on Sundays more than 50,000 vehicles per day were commonly recorded.

The heaviest traffic occurred on Sunday evenings in the summer with pleasure traffic returning to New

[1] A Proposed New Highway from the Westerly end of the Vehicular Tunnel in Jersey City via Kearny and Newark to Elizabeth, January 1925. This report consists of two sections: A Study of the Economic and Other Conditions Which Show the Need of This Proposed New Highway and Which Govern and Control its Design, by F. Lavis, and Studies of Traffic Data and Economic Values, by S. Johannesson.

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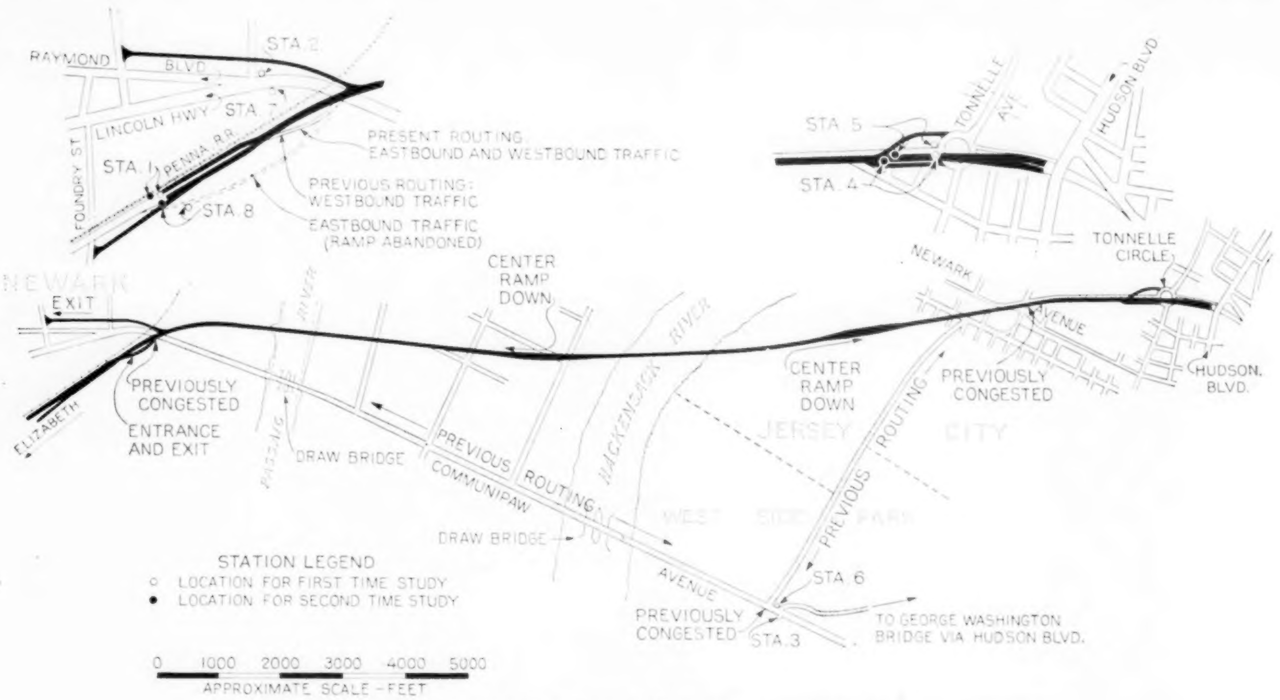

FIGURE 1.—MAP SHOWING OLD ROUTE (STIPPLED) AND NEW VIADUCT ROUTE.

York from the New Jersey shore resorts. Hourly traffic during this time frequently exceeded 2,000 vehicles in one direction. The viaduct which relieves this highly congested section is clear of all intersections at grade, provides at least two lanes for moving traffic in each direction, is high enough to eliminate the necessity of draw bridges and, in addition, has reduced the distance to 3.7 miles.

NEW FIELD SURVEY METHODS DEVELOPED

In order to estimate the vehicle time saved by the viaduct it was necessary to measure the average trip time on the old route and upon the viaduct between the same points. The difference in average trip time multiplied by the number of vehicles benefited represents the total vehicle time saved. The problem of measuring the average trip time on the old route was complicated by a wide variation in the frequency of bridge openings and in the volume of traffic throughout the day. It was necessary to time a sufficiently large number of trips to determine the effect of bridge openings and volume of traffic.

The method adopted involved the listing of vehicle license numbers at both ends of the route together with the time of passage of each vehicle to the nearest minute, and the subsequent matching of these license numbers so as to derive the trip time of each vehicle. The same method was followed to obtain the average trip time upon the viaduct. It was found that a record of only the last four digits of the license number, regardless of State of registration, was sufficient to identify a vehicle in all but a few exceptional cases.

Observation stations were located as shown in figure 1, each position having two stations, one for each direction of traffic. For the time study on the old route, station 8 and station 1 were located at the west end of the viaduct, east-bound vehicles being recorded at station 8 and west-bound vehicles at station 1. Stations 4 and 5, for east-bound and west-bound traffic, respectively, were placed at the opposite end of the route on the west side of Tonnelle Circle. Vehicles were timed from station 8 to station 4, and from station 5 to station 1, and the average trip time between these two pairs of stations was compared with subsequent time observations on the viaduct. A considerable volume of local traffic still uses Communipaw Avenue in traveling between Jersey City and Newark. In order to determine the time saved by this traffic as a result of diversion of through traffic to the viaduct, two additional pairs of stations, 3 and 6, and 7 and 2, were located at the east and west ends, respectively, of this section of the route. Vehicles were timed from station 7 to station 3, and from station 6 to station 2. For the time study of traffic on the viaduct only the two pairs of stations, 8 and 1 at the west end, and 4 and 5 at the east end, were used, with slight changes in location required by the new routing of traffic.

As might be supposed, the field personnel necessary to make such a study was large, particularly so on the old route, where eight stations were established. During periods of heavy traffic a maximum of 38 men were employed, including supervisors. The arrangement of personnel at the various stations was adapted to the physical conditions existing and to the volume of traffic to be recorded. At each station it was necessary to record the volume of traffic, to list separately the license numbers of passenger cars, trucks, and busses, and to call the time minute by minute. At the lighter traffic stations it was sometimes possible for one man to serve as timekeeper and truck and bus observer, but more frequently it was necessary to increase the personnel, especially the observers listing numbers. At the heavy traffic stations two passenger-car observers and two truck and bus observers were required. Usually these observers worked in pairs, one reading numbers to the other. At the west end of the viaduct where traffic was moving at a high speed, it was necessary to assign observers to each lane of traffic. In the time study of

traffic on the viaduct, lack of sufficient space at station 5 made it impossible to record numbers at the point of observation, and observers reading numbers communicated by means of portable telephones with recorders stationed across the roadway.

Recorders listing the license numbers were supplied with small cards, upon which were stamped the station number, the date and the time of day to the nearest minute. One card was used for each minute, and only the license numbers of vehicles passing during that minute were listed on a single card. At the beginning of each day's work, all timekeepers' watches were compared and set, and at frequent intervals during the day they were checked against a watch held by the general supervisor.

In classifying trucks, it was impossible to draw a sharp distinction between light trucks and heavy trucks. Observers were instructed to classify trucks of 2½-ton capacity or less as light trucks and all others as heavy, and reliance was placed upon their experience to make this distinction with reasonable accuracy. The classification of individual trucks at entrance and exit stations was found to be fairly consistent.

FIELD METHODS RESULTED IN SATISFACTORY SAMPLES

Theoretically, if the license numbers of half the vehicles passing are listed at random at each end of a given section of highway, one quarter of the cars can be identified and the travel time determined. In general terms, the percentage of cars identified at both ends will be the product of the percentages of the licenses listed at each end divided by 100. It is obvious that the number of probable matches decreases very rapidly as the efficiency in recording numbers is decreased. A further loss occurs when there are other entrances and exits to the route, not covered by recording stations, as was the case particularly on the old route. Therefore, every effort was made to maintain a high efficiency in listing license numbers. After a short period of training a surprising speed in recording was developed. In heavy traffic the number recorded per minute on a single card consistently exceeded 20 and occasionally exceeded 30.

The field study of the old route before the opening of the viaduct was made on September 24, 25, 26, 27, 28, and October 1 and 2, 1932. These dates included 2 Saturdays, 2 Sundays, and 3 week days. Eight hours of observation were made each day, staggered from day to day to cover the hours of the day from 6 a.m. to 10 p.m. When this schedule was completed, an examination of the data revealed that the volume of traffic and the number of bridge openings during many of the hours of observation duplicated those of other hours. To avoid unnecessary clerical work, subsequent analysis was confined to a selected sample of 19 hours of east-bound and 18 hours of west-bound traffic covering a complete range in volume of traffic and bridge openings.

Tabulation of this sample showed approximately 99,000 license numbers recorded at the eight stations, 85,000 being for passenger cars. During the same hours, the traffic passing these stations totaled 128,000 vehicles, including 112,500 passenger cars. Of the license numbers listed 37,000 were matched, thus giving the trip time of 18,500 vehicles. On the average 77 percent of the passing vehicles were listed, and 29 percent of these vehicles were timed over the route. Even under the difficult conditions prevailing after nightfall the efficiency averaged 24 percent. Under the severest test, heavy east-bound passenger-car traffic on Sunday night, a record of 17 percent was maintained.

Because a very considerable proportion of the vehicles passing through Tonnelle Circle (stations 4 and 5) entered or left the route at Newark Avenue, where there were no observation stations, a fairer measure of the efficiency of the method is to compare the number of timed vehicles with the total traffic entering the west end of Communipaw Avenue through stations 7 and 8 and leaving through stations 1 and 2. On this basis the average efficiency for the entire study was 38 percent.

The High-Level Viaduct was opened to traffic on November 23, 1932. In order to allow traffic to adjust itself to driving conditions on the viaduct and also to obtain a wide range in volume of traffic, observations of trip time were not made until Saturday and Sunday, May 20 and 21, 1933. The method of observation was the same as that described for the old route. Stations 1 and 8 were located at approximately the same points as in the previous study. Stations 4 and 5 were placed at the junction of the viaduct and the two ramps leading to and from Tonnelle Circle. This point was about 500 feet west of the previous location, a move so slight that its effect on the comparative trip time could be safely ignored. No additional observations of trip time on the old route were made, as the previous observations were sufficient to estimate the

TYPICAL CONGESTION ON NEWARK AVENUE AT INTERSECTION WITH U.S. NO. 1 BEFORE OPENING OF VIADUCT.

trip time under the conditions existing on the old route after the viaduct was opened.

The number of vehicles entering or leaving the viaduct between the stations was less than on the old route and the proportion of cars timed was therefore higher. During 11 hours of observation 29,700 license numbers were recorded at the 4 stations out of a possible 34,000. Of the numbers listed 16,800 were matched, giving the trip time of 8,400 vehicles. On the average 87 percent of the passing vehicles were listed, and 49 percent were timed.

The large number of licenses listed during the observations on the old route and the variations in trip time caused by the bridge openings would have made the matching of numbers by inspection an almost impossible task. This work was greatly facilitated by the use of sorting and tabulating machines, the field record being transferred to punch cards and the matching accomplished mechanically. The license numbers listed in the time study on the viaduct were matched by inspec-

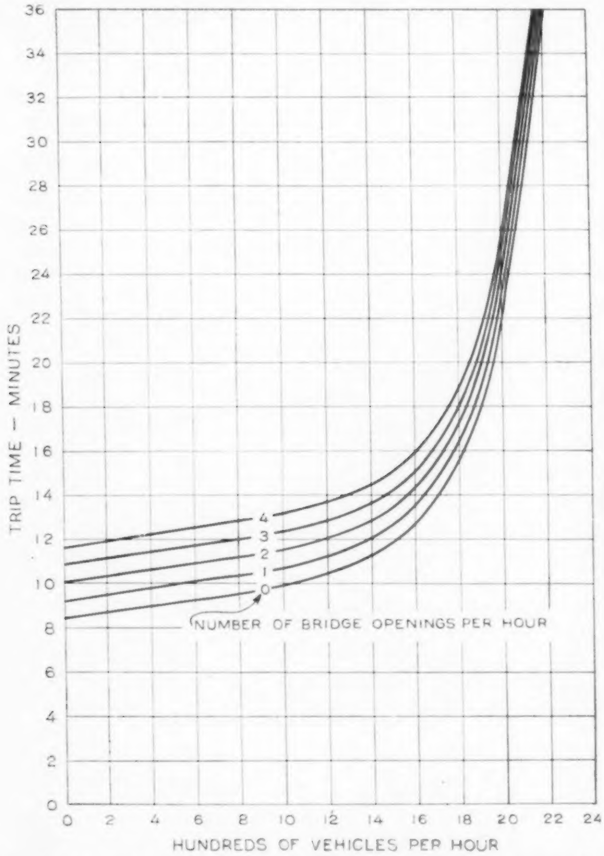

FIGURE 2.—VARIATION IN THE TRIP TIME OF PASSENGER CARS ON THE GROUND-LEVEL ROUTE BETWEEN TONNELLE CIRCLE AND THE WEST END OF THE VIADUCT, WITH VOLUME OF TRAFFIC AND FREQUENCY OF BRIDGE OPENINGS.

tion as the number of them was much smaller with little variation in individual trip times.

DEFINITE RELATION FOUND BETWEEN TRIP TIME, VOLUME OF TRAFFIC AND BRIDGE OPENINGS

Data from the field records as analyzed and tabulated consisted, for each selected period of time and for each desired combination of stations, of a chronological listing of vehicles according to time of arrival at the entering station together with trip time to the leaving station. The fluctuation in trip time from minute to minute could be observed and compared to variation in traffic volume, and also, on the old route, to the number of bridge openings. This tabulation was divided into hourly periods arranged to give the greatest possible variation in traffic volume and the number of bridge openings, and the trip times in each hour period were averaged. The average times were then plotted against traffic volume and bridge openings during the corresponding periods.

The traffic volume at the Hackensack River Bridge was used in estimating the average daily traffic on the old route. The openings of the two bridges were combined, the assumption being that the interruption to traffic was equivalent to that of one bridge. The graph indicated a definite relationship between trip time, traffic volume, and bridge openings, and a series of curves was fitted to the data by means of a multiple correlation to establish this relationship mathematically. Similar curves were fitted to the data for trip time on the viaduct.

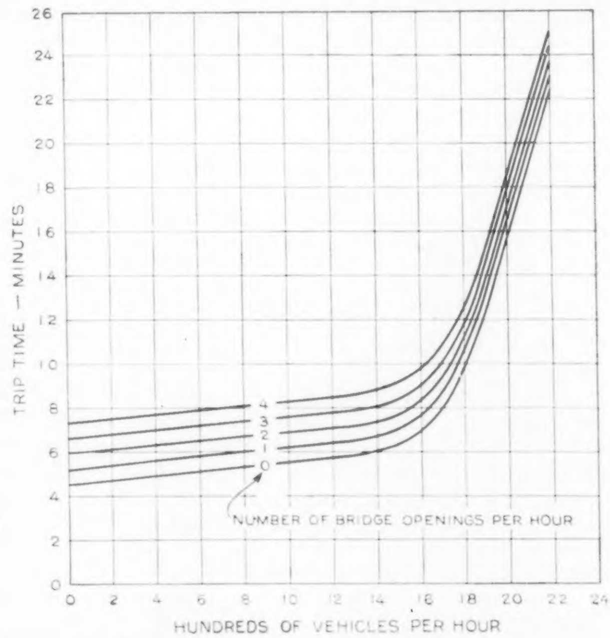

FIGURE 3.—VARIATION IN THE TRIP TIME OF PASSENGER CARS ON THE GROUND-LEVEL ROUTE BETWEEN WEST SIDE PARK AND THE WEST END OF THE VIADUCT, WITH VOLUME OF TRAFFIC AND FREQUENCY OF BRIDGE OPENINGS.

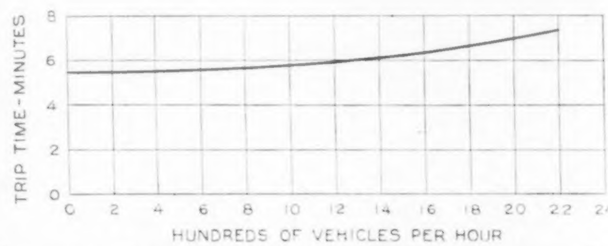

FIGURE 4.—VARIATION IN THE TRIP TIME OF PASSENGER CARS ON THE VIADUCT, WITH VOLUME OF TRAFFIC.

These curves showed the effect of the volume of traffic on the old route as measured at the Hackensack River Bridge and the combined number of bridge openings per hour at both bridges on the normal trip time for passenger cars, light trucks, and heavy trucks between the west end of the viaduct and Tonnelle Circle, and also for the same classes of vehicles along Communipaw Avenue. Figures 2, 3, and 4 show curves for passenger cars only on the old route and on the viaduct. The curves give the normal trip time on the old route for any combination of volume of traffic per hour from 0 to 2,200, and from 0 to 4 bridge openings per hour. They show the normal trip time on the viaduct for any volume of traffic from 0 to 2,200 vehicles per hour. This range in traffic volume and rate of bridge openings covered all observed fluctuations.

In order to establish the weighted average trip time throughout the day it was necessary to estimate accurately the volume of traffic during each hour of the day for the various classes of vehicles in each direction, and also, for traffic on the old route, the average number of bridge openings for every hour of the day. Knowing this, the trip time for every hour of the day for any type of vehicle could be determined from the curves. The average trip time for each type of vehicle was obtained by multiplying trip time for each hour and for each direction by the number of vehicles for each

General View of Viaduct. The Communipaw Avenue Route Can Be Seen at the Right.

corresponding hour and direction, totaling these products and dividing by the total number of vehicles of the given type for the day. Weighted average trip times of passenger cars, light trucks, and heavy trucks were thus obtained for week days, Saturdays, and Sundays and holidays. The trip time of busses was originally recorded separately, but the number of bus trips was insufficient to establish a definite relationship with traffic or bridge openings. As the busses constituted a small percentage of total traffic, they were considered as passenger cars in this analysis. The trip time of busses appears to approximate very closely that of passenger cars, and if it is desired to estimate the time savings to busses, the trip-time curves of passenger cars may be used.

It was evident that in order to establish reliable averages for traffic during each hour of the day careful estimates were necessary. Numerous traffic counts made by the State Highway Department were available for the year 1932. These records consisted largely of counts at the Hackensack River Bridge, made in 8-hour shifts, and gave the volume of traffic per hour in either direction, classified as passenger cars, light trucks, and heavy trucks. In numerous cases shifts were arranged to give a continuous 16-hour count and for several consecutive days 24-hour counts were available. From these counts it was possible to compute the normal percentage of total daily traffic in each 8-hour shift, and to raise all counts to their 24-hour equivalents.

TRAFFIC COUNTS CORRECTED FOR SEASONAL VARIATION BY USE OF HOLLAND TUNNEL RECORDS

The first step in analyzing the available traffic records was to estimate the average daily traffic east-bound and west-bound for week days, Saturdays, and Sundays and holidays. While the traffic records were large in number the counts had not been made on a schedule such that a simple average of counts would give proper weight to the seasonal variations in traffic. However, complete and detailed traffic records for every day in the year at the Holland Tunnel were made available through the courtesy of the Port of New York Authority. A comparison of the individual traffic counts at the Hackensack River Bridge (raised to a 24-hour basis) with Holland Tunnel records for the same days, established that there was a constant ratio between the traffic volumes at the two points and that the seasonal fluctuations were similar. The average ratios of Hackensack River Bridge counts to Holland Tunnel counts were computed for both directions on week days, Saturdays, and Sundays and holidays. These average ratios were then applied to the 24-hour counts at the Holland Tunnel for the corresponding days (obtained from the complete year's record) to estimate the average daily traffic at the Hackensack River Bridge as shown in table 1.

While large variations occurred in the total daily traffic in various months of the year, the percentage distribution through the hours of the day remained constant. It was possible to compute from these records a reliable index showing the percentage of total daily traffic traveling during each hour of the day for week days, Saturdays, and Sundays and holidays for both east-bound and west-bound traffic. These indices when applied to the daily traffic gave estimates of the average hourly traffic of all classes of vehicles.

The New Jersey State Highway Commission maintains accurate records of the operation of all draw bridges under its jurisdiction, which show the time of occurrence and the duration of every draw opening. An examination of the records for the Hackensack and Passaic River Bridges for 1932 showed that openings of 5 minutes' duration greatly predominated, regard-

TABLE 1.—*Estimates of average daily traffic at the Hackensack River Bridge during 1932*

Day and direction	Average daily traffic, Holland Tunnel	Ratio Hackensack River Bridge traffic to Holland Tunnel traffic	Estimated average daily traffic at Hackensack River Bridge
Week day:			
East-bound	14, 339	1. 314	18, 800
West-bound	14, 175	1. 312	18, 600
Total	28, 514	1. 312	37, 400
Saturday:			
East-bound	15, 891	1. 244	19, 800
West-bound	17, 467	1. 206	21, 000
Total	33, 357	1. 222	40, 800
Sundays and holidays:			
East-bound	20, 747	1. 191	24, 700
West-bound	19, 821	1. 240	24, 600
Total	40, 568	1. 214	49, 300

Total yearly traffic:	*Vehicles*
Holland Tunnel (recorded)	11, 433, 847
Hackensack River Bridge (estimated)	14, 600, 000

less of time of day, and the average duration of all openings was very nearly five minutes. Accordingly, the average opening was assumed to be 5 minutes, and computations were based on the number of openings rather than their duration. As previously explained, the two bridges were treated as a single bridge. The combined average number of openings for every hour of the day was computed for week days (including Saturdays), and for Sundays and holidays. Saturdays were included with week days, as openings on Saturdays were found to correspond closely with those of other week days. According to the New Jersey State Highway Commission, the total number of bridge openings of these two bridges during 1932 was less than in any other year since 1926 and was only one half the number during 1929. There is every indication of an increasing number of openings in future years, and consequently more frequent interruptions to traffic.

LARGE VOLUME OF TRAFFIC DIVERTED TO VIADUCT

These data in conjunction with the estimates of the hourly volume of traffic were used to estimate the various average trip times during every hour of the day, and from these the weighted average trip times. Table 2 shows the steps in the computation of the weighted average trip time on the old route between the west end of the viaduct and Tonnelle Circle for east-bound passenger cars on a week day. Column 1 of the table is the estimate of total hourly traffic at the Hackensack River Bridge, while column 2 is the average number of bridge openings per hour. The use of the figures in these two columns in conjunction with the trip-time curves, figure 2, results in the average trip time for each hour of the day, column 3. Car-minutes are obtained by multiplying the trip time for each hour by the number of passenger cars per hour, column 4. The weighted average trip time for the day is total car-minutes divided by total cars, which in this case is 12.1 minutes.

Having established an accurate estimate of average daily traffic at the Hackensack River Bridge it was necessary to estimate the division of traffic at the intersection of Communipaw Avenue and the highway to Tonnelle Circle near West Side Park. Only scattering

TABLE 2.—*Computation of weighted average trip time for week-day east-bound passenger cars traveling on the ground-level route between the west end of the viaduct and Tonnelle Circle*

Hours	(1) Total traffic Hackensack Bridge	(2) Number of bridge openings per hour	(3) Trip time of passenger cars, minutes	(4) Number of passenger cars	(3)×(4) Car-minutes per hour
12 to 1 a.m.	420	0. 95	9. 7	364	3, 531
1 to 2 a.m.	280	. 95	9. 6	233	2, 237
2 to 3 a.m.	150	. 82	9. 2	108	994
3 to 4 a.m.	140	. 74	9. 1	90	819
4 to 5 a.m.	150	. 97	9. 4	84	790
5 to 6 a.m.	200	1. 39	9. 9	101	1, 000
6 to 7 a.m.	460	2. 20	11. 0	263	2, 893
7 to 8 a.m.	870	2. 91	12. 1	572	6, 921
8 to 9 a.m.	1, 120	2. 92	12. 5	798	9, 975
9 to 10 a.m.	1, 240	3. 09	13. 1	908	11, 895
10 to 11 a.m.	1, 210	3. 25	13. 1	897	11, 751
11 to 12 a.m.	1, 130	3. 14	12. 8	829	10, 611
12 to 1 p.m.	980	3. 60	12. 7	715	9, 080
1 to 2 p.m.	980	3. 27	12. 5	710	8, 875
2 to 3 p.m.	920	3. 01	12. 2	680	8, 296
3 to 4 p.m.	1, 100	2. 76	12. 3	849	10, 443
4 to 5 p.m.	1, 380	2. 73	13. 3	1, 138	15, 135
5 to 6 p.m.	1, 430	2. 43	13. 3	1, 207	16, 053
6 to 7 p.m.	1, 130	2. 37	12. 1	956	11, 568
7 to 8 p.m.	1, 010	1. 78	11. 4	844	9, 622
8 to 9 p.m.	850	1. 53	10. 9	706	7, 695
9 to 10 p.m.	730	1. 22	10. 5	598	6, 279
10 to 11 p.m.	480	1. 44	10. 4	437	4, 545
11 to 12 p.m.	440	0. 86	9. 6	398	3, 821
Total	18, 800	----------	----------	14, 485	174, 829

Weighted average trip time=174,829 ÷ 14, 485=12.1 minutes.

counts were available at this point, but they were sufficient to establish a reliable percentage.

The number of traffic counts at the Hackensack River Bridge after the opening of the viaduct was insufficient to set up accurate ratios with Holland Tunnel traffic. However, using the percentage distribution of traffic through the hours of the day as determined from the previous records, it was possible to raise the traffic counts to estimated 24-hour traffic, and to correct this estimate for seasonal fluctuations by means of the seasonal index for Holland Tunnel traffic. In no case did these corrected individual estimates differ materially from each other and it was felt that an average of them would indicate the daily traffic accurately. Table 3 shows these estimates of traffic before and after the opening of the viaduct. Estimates are given of the volume of traffic between Tonnelle Circle and the west end of the viaduct, and between West Side Park and the west end of the viaduct along Communipaw Avenue. The total of these equals the estimated traffic at the Hackensack River Bridge shown at the right of the table. The difference in these two estimates, that is, the reduction in traffic volume on the old route after the opening of the viaduct, appears at the bottom of the table.

VIADUCT RESULTS IN LARGE SAVING IN VEHICLE TIME

The great difference in the volume of traffic traveling between Tonnelle Circle and the west end of the viaduct, before and after the opening of the viaduct, may be considered as a measure of the traffic which has been diverted to the viaduct, and which unquestionably benefits by the saving in time between these points. Table 3, however, shows that this difference in traffic to and from Tonnelle Circle accounts for only a part of the total reduction in traffic on Communipaw Avenue at the Hackensack River Bridge. This may be explained by the fact that previous to the opening of the viaduct, traffic destined to the George Washington Bridge and towns north of Tonnelle Circle was routed

TABLE 3.—*Daily traffic at the Hackensack River Bridge and the amount of this traffic entering and leaving the route at Tonnelle Circle and at the West Side Park*

	To and from Tonnelle Circle				To and from West Side Park				Total at the Hackensack River Bridge			
	Passenger cars	Light trucks	Heavy trucks	Total	Passenger cars	Light trucks	Heavy trucks	Total	Passenger cars	Light trucks	Heavy trucks	Total
DAILY TRAFFIC BEFORE THE OPENING OF THE VIADUCT												
Week day	14, 485	1, 625	1, 950	18, 060	14, 485	2, 155	2, 700	19, 340	28, 970	3, 780	4, 650	37, 400
Saturday	23, 212	1, 193	1, 352	25, 757	12, 498	1, 192	1, 353	15, 043	35, 710	2, 385	2, 705	40, 800
Sundays and holidays	30, 596	688	426	31, 710	16, 474	689	427	17, 590	47, 070	1, 377	853	49, 300
DAILY TRAFFIC AFTER THE OPENING OF THE VIADUCT												
Week day	790	376	634	1, 800	10, 500	1, 600	2, 700	14, 800	11, 290	1, 976	3, 334	16, 600
Saturday	1, 936	236	641	2, 813	11, 894	940	1, 353	14, 187	13, 830	1, 176	1, 994	17, 000
Sundays and holidays	796	18	16	830	9, 144	334	292	9, 770	9, 940	352	308	10, 600
DAILY TRAFFIC DIVERTED TO THE VIADUCT												
Week day	13, 695	1, 249	1, 316	16, 260	3, 985	555	0	4, 540	17, 680	1, 804	1, 316	20, 800
Saturday	21, 276	957	711	22, 944	604	252	0	856	21, 880	1, 209	711	23, 800
Sundays and holidays	29, 800	670	410	30, 880	7, 330	355	135	7, 820	37, 130	1, 025	545	38, 700

through West Side Park to Hudson Boulevard to reduce congestion at Tonnelle Circle. All such traffic is undoubtedly now using the viaduct, and it is reasonable to assume that it benefits by a saving in trip time at least as great as that of the traffic which was routed through Tonnelle Circle.

Accordingly, two estimates have been prepared for the total vehicular time saved by the viaduct. The first of these includes only savings to those vehicles which previously traveled between Tonnelle Circle and the west end of the viaduct, and is termed the minimum estimate. The second, or maximum estimate, is based on the total reduction of traffic at the Hackensack River Bridge, with the assumption that all of these vehicles have been diverted to the viaduct and benefit by a saving in trip time at least equal to that of the traffic previously routed through Tonnelle Circle.

Table 4 is a comparison of the weighted average trip time of the various classes of vehicles before and after the opening of the viaduct. It is evident that in addition to a considerable time saving to those vehicles which now use the viaduct, there is also a noticeable time saving per trip between various points on the old route because of the lessened volume of traffic now existing.

Table 5 is an estimate of the total yearly saving in vehicle minutes to this traffic. The average daily traffic multiplied by the saving per trip in minutes gives the average vehicle minutes saved per day and this multiplied by the number of days per year gives the total saving per year in vehicle minutes. For example, table 3 shows that on week days 790 passenger cars per day now travel on the old route between Tonnelle Circle and the west end of the viaduct. From table 4 the weighted average trip time for vehicles making this trip before the opening of the viaduct was 12.0 minutes, and after the opening of the viaduct 11.0 minutes, a saving of 1.0 minute per trip. Seven hundred and ninety vehicles per day multiplied by 1.0 minute gives 790 vehicle-minutes saved each week day, multiplied by 254 gives an estimate of 201,000 vehicle-minutes per year. The total yearly saving for all types of vehicles resulting from reduced traffic congestion on the old route is 5,542,000 vehicle-minutes per year.

TABLE 4.—*Summary of average trip times in minutes*

	Passenger cars			Light trucks			Heavy trucks		
	Before opening viaduct	After opening viaduct	Saving in time	Before opening viaduct	After opening viaduct	Saving in time	Before opening viaduct	After opening viaduct	Saving in time
ON GROUND-LEVEL ROUTE BETWEEN WEST SIDE PARK AND WEST END OF VIADUCT									
Week days	7. 2	6. 6	0. 6	8. 2	7. 5	0. 7	8. 9	8. 2	0. 7
Saturdays	7. 3	6. 6	. 7	8. 4	7. 6	. 8	9. 2	8. 4	. 8
Sundays and holidays	8. 7	5. 4	3. 3	7. 9	6. 0	1. 9	10. 5	6. 7	3. 8
ON GROUND-LEVEL ROUTE BETWEEN TONNELLE CIRCLE AND WEST END OF VIADUCT									
Week days	12. 0	11. 0	1. 0	13. 9	13. 0	0. 9	14. 9	14. 3	0. 6
Saturdays	12. 2	11. 0	1. 2	14. 2	13. 0	1. 2	15. 3	14. 5	. 8
Sundays and holidays	14. 0	9. 5	4. 5	13. 9	11. 0	2. 9	18. 5	12. 4	6. 1
ON GROUND-LEVEL ROUTE AND ON VIADUCT BETWEEN TONNELLE CIRCLE AND WEST END OF VIADUCT									
Week days	[1] 12. 0	[2] 5. 7	6. 3	[1] 13. 9	[2] 6. 4	7. 5	[1] 14. 9	[2] 7. 5	7. 4
Saturdays	[1] 12. 2	[2] 5. 8	6. 4	[1] 14. 2	[2] 6. 4	7. 8	[1] 15. 3	[2] 7. 6	7. 7
Sundays and holidays	[1] 14. 0	[2] 6. 0	8. 0	[1] 13. 9	[2] 6. 6	7. 3	[1] 18. 5	[2] 8. 0	10. 5

[1] On ground-level route.
[2] On viaduct.

Table 6 is an estimate of the yearly saving prepared in the same manner for the vehicles which previously traveled on the old route between Tonnelle Circle and the west end of the viaduct and which now use the viaduct. This estimate, which has been termed the minimum estimate, is 49,130,000 vehicle-minutes per year. To this is added the saving to vehicles still using the ground-level route, the final minimum estimate being 54,672,000 vehicle-minutes saved per year.

Table 7 is an estimate of the yearly saving if the saving per trip is assumed to apply to the total reduction in traffic on the old route, the maximum estimate. This estimate is 60,563,000 vehicle-minutes per year, or 66,105,000 when the saving to vehicles still using the ground-level route is added. In all of these tables the total estimated saving is a sum of separate estimates for passenger cars, light trucks, and heavy trucks, and

TABLE 5.—*Estimate of time saved per year by vehicles using the ground-level route after the opening of the viaduct*

BETWEEN TONNELLE CIRCLE AND THE WEST END OF THE VIADUCT

	Daily traffic	Minutes saved per trip	Vehicle-minutes saved		
			Per day	Number of days	Per year
Week day:					
Passenger cars	790	1.0	790	254	201,000
Light trucks	376	.9	338	254	86,000
Heavy trucks	634	.6	380	254	97,000
Saturday:					
Passenger cars	1,936	1.2	2,323	52	121,000
Light trucks	236	1.2	283	52	15,000
Heavy trucks	641	.8	513	52	27,000
Sundays and holidays:					
Passenger cars	796	4.5	3,582	59	211,000
Light trucks	18	2.9	52	59	3,000
Heavy trucks	16	6.1	98	59	6,000

BETWEEN WEST SIDE PARK AND THE WEST END OF THE VIADUCT

	Daily traffic	Minutes saved per trip	Per day	Number of days	Per year
Week day:					
Passenger cars	10,500	0.6	6,300	254	1,600,000
Light trucks	1,600	.7	1,120	254	284,000
Heavy trucks	2,700	.7	1,890	254	480,000
Saturday:					
Passenger cars	11,894	.7	8,326	52	433,000
Light trucks	940	.8	752	52	39,000
Heavy trucks	1,353	.8	1,082	52	56,000
Sundays and holidays:					
Passenger cars	9,144	3.3	30,175	59	1,780,000
Light trucks	334	1.9	635	59	38,000
Heavy trucks	292	3.8	1,110	59	65,000

Total vehicle-minutes saved per year

Passenger cars	4,346,000
Light trucks	465,000
Heavy trucks	731,000
Total	5,542,000

these estimates are shown in detail. The yearly savings for the various classes of vehicles for the minimum and maximum estimates are summarized in table 8.

The construction cost of the viaduct was approximately $19,300,000. In the original economic study by the State authorities it was assumed that the money value of the prospective savings could be capitalized

TABLE 6.—*Minimum estimate of time saved per year by vehicles which previously traveled on the ground-level route between Tonnelle Circle and the west end of the viaduct*

	Daily vehicles	Minutes saved per trip	Vehicle-minutes saved		
			Per day	Number of days	Per year
Week day:					
Passenger cars	13,695	6.3	86,278	254	21,915,000
Light trucks	1,249	7.5	9,368	254	2,379,000
Heavy trucks	1,316	7.4	9,738	254	2,474,000
Saturday:					
Passenger cars	21,276	6.4	136,166	52	7,081,000
Light trucks	957	7.8	7,465	52	388,000
Heavy trucks	711	7.7	5,475	52	285,000
Sundays and holidays:					
Passenger cars	29,800	8.0	238,400	59	14,065,000
Light trucks	670	7.3	4,891	59	289,000
Heavy trucks	410	10.5	4,305	59	254,000

Total vehicle-minutes saved per year

	Passenger cars	Light trucks	Heavy trucks	Total
On the viaduct	43,061,000	3,056,000	3,013,000	49,130,000
On the ground-level route	4,346,000	465,000	731,000	5,542,000
Total	47,407,000	3,521,000	3,744,000	54,672,000

TRAFFIC DELAYED ON COMMUNIPAW AVENUE AS A RESULT OF BRIDGE OPENING.

TABLE 7.—*Maximum estimate of time saved per year by total vehicles diverted to the viaduct from Communipaw Avenue*

	Daily vehicles	Minutes saved per trip	Vehicle-minutes saved		
			Per day	Number of days	Per year
Week day:					
Passenger cars	17,680	6.3	111,384	254	28,292,000
Light trucks	1,804	7.5	13,530	254	3,437,000
Heavy trucks	1,316	7.4	9,738	254	2,473,000
Saturday:					
Passenger cars	21,880	6.4	140,032	52	7,282,000
Light trucks	1,209	7.8	9,430	52	490,000
Heavy trucks	711	7.7	5,475	52	285,000
Sundays and holidays:					
Passenger cars	37,130	8.0	297,040	59	17,525,000
Light trucks	1,025	7.3	7,482	59	441,000
Heavy trucks	545	10.5	5,722	59	338,000

Total vehicle-minutes saved per year

	Passenger cars	Light trucks	Heavy trucks	Total
On the viaduct	53,099,000	4,368,000	3,096,000	60,563,000
On the ground-level route	4,346,000	465,000	731,000	5,542,000
Total	57,445,000	4,833,000	3,827,000	66,105,000

TABLE 8.—*Summary of vehicle-minutes saved per year by type of vehicle*

	Minimum estimate	Maximum estimate
Passenger cars	47,407,000	57,445,000
Light trucks	3,521,000	4,833,000
Heavy trucks	3,744,000	3,827,000
Total	54,672,000	66,105,000

at 6 percent to obtain the sum which might justifiably be spent for the contemplated improvements. Six percent of the actual construction cost is $1,158,000, and in order to justify the construction of the viaduct on the basis of the above minimum and maximum estimates a vehicle-minute must be valued at 2.12 or 1.75 cents.

CONSTRUCTION OF VIADUCT ADVANTAGEOUS TO TRAFFIC ON OTHER ROUTES

It is emphasized that the above estimates of time saved do not include all the savings which may be credited to the viaduct. No estimate of the value of shortened travel distance has been made, and the traffic on the viaduct to which the average saving in trip time was applied is not the total volume of traffic actually using the viaduct. For the maximum estimate the volume used was 20,800 per day for week days, 23,800 per day for Saturdays, and 38,700 per day for Sundays and holidays. From the most recent counts made on the viaduct it is probable that the actual traffic for these days is 30,000, 35,000, and 45,000 vehicles per day. The viaduct undoubtedly has attracted a considerable volume of traffic which previously avoided the route entirely because of the congestion, and while no estimate is possible of the saving in time enjoyed by this additional traffic, it must be considerable. There is also every reason to believe that the traffic on the viaduct will increase during the next few years to a volume which could not have been adequately served by the old route.

Neither the gross figures of estimated savings nor the saving in the average time per trip gives the complete picture of traffic congestion on the old route. The intensity of this congestion during hours of peak traffic is illustrated by the time study on Sunday evening, October 2. From 6:30 p.m. on that day to 9:00 p.m. east-bound traffic toward New York on Communipaw Avenue exceeded 1,800 vehicles per hour and reached a maximum of 2,100, while the bridges were opened four times for a total of 20 minutes. The average trip time of passenger cars from the west end of the viaduct to Tonnelle Circle for the whole period was 29 minutes, while the trip along Communipaw Avenue required 19 minutes. During a comparable period on the viaduct, Sunday, May 21, 1933, the volume of east-bound traffic toward New York was equally heavy, but the average trip time of passenger cars was only 6.7 minutes, and traffic congestion was not noticeable.

The curves for average trip time of passenger cars on the old route in figure 2, should be compared with the same curve for the trip time on the viaduct, figure 4. On the old route, even without bridge openings, the curve for trip time rises very rapidly when the traffic volume exceeds 1,300 vehicles per hour, indicating congestion beyond that point. On the viaduct, however, the curve of trip time does not show any such marked increase up to 2,200 vehicles per hour, the maximum traffic observed. On the old route during the average week day, traffic exceeded 1,300 vehicles per hour in one direction or both during 2 hours of the day, on Saturdays during 5 hours, and on Sundays and holidays during 13 hours, and the average trip time of passenger cars during these hours was 13.2, 14.6, and 17.9 minutes, respectively. On the viaduct during these same hours the average trip time was 5.8, 6.0, and 6.3 minutes.

The volume of traffic on the old route has been so much reduced that even during the periods of heaviest traffic it does not exceed an average of 600 vehicles per hour in one direction on Communipaw Avenue and probably not more than 100 vehicles per hour on the section north from Communipaw Avenue to Newark Avenue. The result is much greater freedom of movement for local traffic, particularly at the previously congested intersections. The improvement of conditions at the junction where Newark Avenue crosses the old route is an illustration of such an advantage.

Newark Avenue (see fig. 1) is the principal artery to Jersey City and the Holland Tunnel for two important local routes from the west: the Belleville Turnpike, serving the suburban communities of Montclair, Glen Ridge, Bloomfield, and Belleville; and the Jersey City and Newark Turnpike, serving the northern section of Newark and the Oranges. In consequence, there is a considerable volume of traffic on Newark Avenue west of its intersection with the old route, only a comparatively small amount of which has been attracted to the viaduct. East of the intersection, the volume of traffic is considerably less, as a large part of the east-bound traffic turns left from Newark Avenue and proceeds through Tonnelle Circle, while the west-bound traffic is increased by a number of vehicles from Tonnelle Circle turning right into Newark Avenue. Previous to the opening of the viaduct, the large volume of east-bound traffic and the heavy left-turn movement, in conflict with an even larger flow of cross traffic were the cause of a great deal of congestion. Traffic was occasionally blocked in a standing line as far east as Tonnelle Circle, a distance of nearly one half mile, while

east-bound traffic on Newark Avenue not infrequently was blocked in two lanes for more than one quarter of a mile.

The transfer of through traffic to the viaduct has largely eliminated congestion at this intersection and has resulted in a material time saving to traffic using Newark Avenue. The relative magnitude of this saving was obtained from detailed studies of travel time on Newark Avenue during several hours of peak traffic in the first and second general time studies. An electric time-recording device was used to determine the travel time of vehicles to the nearest second over a distance which included all waiting and delay at the intersection. East-bound traffic was timed through the intersection from a point approximately 800 feet west, while west-bound traffic was timed from a point about 350 feet east of the intersection.

The time previously required for the average vehicle on Newark Avenue to travel these distances during hours of peak traffic was 74.9 seconds east-bound and 56.3 seconds west-bound. These averages are based on movement of 4,700 vehicles east-bound and 1,200 vehicles west-bound, and the average hourly flow during the observations was 800 and 300. After the viaduct was opened, 2,500 east-bound vehicles averaged 34.6 seconds over the same distance and 400 west-bound vehicles averaged 22.4 seconds. The corresponding hourly rates were 700 and 250. This indicates that for nearly the same volume on Newark Avenue there has been a reduction in the time required to pass through the intersection of 40.3 seconds per car or 53 percent for east-bound traffic, and 33.9 seconds or 60 percent for west-bound traffic. These results apply to only a limited period of observation, and no effort was made to calculate the saving on a yearly basis. It is clear, however, that it constitutes a very considerable item of incidental benefit resulting from the new viaduct construction.

RESULTS OF STUDIES ON ROGUE RIVER BRIDGE REPORTED

The final report on Application of Freyssinet Method of Concrete Arch Construction to the Rogue River Bridge in Oregon, by Albin L. Gemeny, of the Bureau of Public Roads, and C. B. McCullough, of the Oregon State Highway Commission, has been published as Bulletin No. 2 of the Oregon State Highway Commission.

In the Freyssinet method hydraulic jacks are placed in open radial joints appropriately located in arch ribs and used to produce deformations in the arch.

The deformations are controlled so as to produce the most desirable distribution of stress in the ribs, eliminating or mitigating the effects of volume changes in the concrete, foundation movements and the indeterminate effect of the spandrel structure. The jacks may be placed at one or more joints. For symmetrical arches a joint at the crown is usually sufficient. After the arch has been adjusted to the desired position, the joint is filled and the jacks removed, after which the structure acts as the usual type of fixed arch. If there is reason to believe that future adjustments may be necessary the jack emplacements may be preserved for this purpose.

The Rogue River Bridge is a Federal-aid project constructed jointly by the Bureau of Public Roads and the Oregon State Highway Commission. It consists of seven 230-foot spans with a 3-span central group on elastic piers and a 2-span group at each end.

During the jacking operations careful measurements were made of deformations and strains which occurred in the arches so that, at all times, the effect of the jacking was known. The report contains these data in the form of charts and tables.

Satisfactory results were obtained with the Freyssinet method in economy of bridge construction and also from the standpoint of certainty of stress action.

The Bureau of Public Roads has available a limited supply of the report for distribution to libraries, highway bridge engineers, and instructors in bridge design.

THE EFFECT OF CONTROL METHODS ON TRAFFIC FLOW

Reported by E. H. HOLMES, Assistant Highway Economist, Division of Highway Transport, United States Bureau of Public Roads

FIGURE 1.—INTERSECTION OF CONSTITUTION AVENUE AND SEVENTEENTH STREET. TRAFFIC MOVING ON CONSTITUTION AVENUE.

STREET and highway intersections not only determine the capacity of the intersecting ways, but also may cause serious delay to traffic. The intersection of Constitution Avenue and Seventeenth Street in Washington, D.C. (fig. 1), offered unusual opportunity to analyze the delay caused by different control methods to a moderately heavy flow of traffic. This is but one of a series of intersection studies now being conducted by the Bureau of Public Roads, but the methods used in the collection of the data and the results obtained seem to justify a special report on this particular study.

VOLUME OF TRAFFIC NEARLY CONSTANT DURING PERIOD OF STUDY

The steady flow of traffic, both passenger and commercial, a flexible control mechanism and the absence of other controlled intersections in the vicinity made this an ideal intersection for such a study. In addition to vehicle-actuated control, the mechanism permitted fixed-time control with intervals on either street ranging from 15 seconds to 70 seconds, irrespective of the interval length on the other. Cooperation of the Park Police made possible the use of officer control, and also the study of traffic under no-control. The one-way street entering from the park (fig. 2) was shut off during the study, to provide a true four-way intersection.

The hours selected for the study were from 9:30 a.m. to 4:15 p.m. This period excluded the morning and afternoon rush hours and permitted the timing of a volume of traffic nearly constant at about 2,000 vehicles per hour. During this period the effects of left turns and of pedestrian movement, often considerable factors, were negligible. Rush hour traffic was neglected, because the intent of the study was to compare the time of vehicles under a constant volume with variable control methods, rather than to determine how the time might vary with volume; and because the rate of change of volume was so great during the rush hour that the flow would not remain constant over a long enough period to permit analysis of the lost time for any given volume.

In the passage of traffic through an intersection, time may be lost in stopping, in deceleration and acceleration, and possibly in slower than normal driving in anticipation of a signal change. The distance within which these delays occur may be called the zone of influence of the intersection and varies in length with the intersection, and with the speed of traffic. A graphic time recorder was used to record all vehicles as they entered and left the zone of influence, from which the average time per vehicle was determined as described in the Appendix.

During the course of observations at this intersection, carried on during the summer of 1932, the movement of traffic under no-control, officer control, vehicle-actuated control, and under 17 different fixed-time controls was studied. Each timing or control method was studied for a minimum of 2 to 3 hours, while certain control methods were observed for two or more days. The

time spent in actual collection of data amounted to about 56 hours, during which over 100,000 vehicles were timed and otherwise noted during their passage through the intersection.

Analysis of the time recorder charts showed the time of passage for the average vehicle entering on each of the four ways for each control method. These results are summarized in table 1, together with the average, weighted according to the number of vehicles, for each street and finally for the entire intersection. Since Constitution Avenue carried, roughly, twice the volume on Seventeenth Street, those control methods which gave a lower time for the Constitution Avenue traffic showed a correspondingly low figure for the average time for all vehicles.

TABLE 1.—*Average time of vehicle passage through zone of influence of intersection in seconds*

Timing		Constitution Avenue			Seventeenth Street			Both streets
Constitution Avenue	Seventeenth Street	West	East	Both directions	North	South	Both directions	
[1]	[1]	23.8	25.9	24.9	30.1	28.2	29.1	26.3
[2]	[2]	26.8	29.1	28.0	34.6	33.2	33.9	29.9
15	15	29.3	32.2	30.9	32.6	32.9	32.8	31.5
[3]	[3]	28.9	30.6	29.8	35.3	35.3	35.3	31.6
20	20	31.4	32.4	31.9	33.5	32.0	32.7	32.2
40	20	27.6	28.9	28.3	42.0	41.2	41.6	32.7
30	15	29.5	30.7	30.2	41.1	39.7	40.4	33.5
30	20	30.4	31.3	30.9	41.0	38.3	39.6	33.8
15	30	35.8	38.0	37.0	30.9	29.1	30.0	34.9
30	30	33.7	34.8	34.3	37.2	35.5	36.2	34.9
40	30	31.3	33.3	32.4	41.5	41.7	41.6	35.3
20	30	37.0	36.6	36.8	36.0	34.3	35.1	36.2
60	30	29.9	30.9	30.5	51.4	50.8	51.1	37.1
40	40	36.9	38.0	37.3	38.9	38.9	38.9	37.8
70	30	28.4	29.0	28.7	61.1	55.7	58.3	39.0
50	50	41.7	40.9	41.3	40.6	40.2	40.4	41.0
60	45	35.9	38.4	37.3	51.1	49.5	50.3	41.4
30	50	46.0	46.8	46.4	32.9	32.0	32.5	41.6
60	60	44.1	45.1	44.6	48.6	45.3	47.0	45.4
30	70	56.1	57.3	56.7	32.6	31.7	32.1	48.6
AVERAGE VEHICLES PER HOUR								
--------	--------	625	740	1,365	320	350	670	2,035

[1] No control.
[2] Officer control.
[3] Traffic-actuated control.

SHORT LIGHT INTERVALS BEST UNDER FIXED-TIME CONTROL

From the figures in table 1 there has been derived the following equation:

$$T = 26.4 + 0.04x + 0.28y \tag{1}$$

where T = time for the average vehicle to travel 600 feet, including the intersection.

x = green interval on Constitution Avenue (including 3-second amber overlap).

y = green interval on Seventeenth Street (including 3-second amber overlap).

The equation was obtained from a multiple correlation of three variables, one T, dependent, and the others, x and y, independent variables.

This equation shows that lengthening the light interval on either or both streets increases the average time of passage. It is to be expected that lengthening the interval on Seventeenth Street, which carries only one third of the traffic through the intersection, would increase the time of the average vehicle since stopping the heavy traffic to permit the light traffic to flow must necessarily result in an increased time per vehicle when the average is appropriately weighted. What is not expected, however, is that extending the interval on Constitution Avenue, the heavily traveled street, also results in an increased time for the average vehicle.

FIGURE 2.—PLAN OF INTERSECTION OF CONSTITUTION AVENUE AND SEVENTEENTH STREET.

Comparison of the actual time period for various light intervals with the time periods derived with equation 1 shows that through the middle of the range of light intervals studied the actual values are less than the theoretical, whereas in the upper and lower ranges the actual times are higher.

It is probable that decreasing the light interval below a certain figure would result in increasing the running time, and that inordinately long intervals increase the running time disproportionately. Figures 3, 4, and 5 show the effect of varying the light interval. Figure 3 shows the effect of increasing the cycle length, using the same cycle on both streets. With an interval length of 15 seconds (12 green plus 3 green and amber) on each street, or a total cycle length of 30 seconds, the average vehicle requires 31.5 seconds to traverse the zone of influence of the intersection. Maintaining this same 1 to 1 proportioning, a cycle of 120 seconds increases the running time to over 45 seconds per vehicle, an increase of nearly 50 percent.

NO ADVANTAGE IN FAVORING HEAVILY TRAVELED STREET WITH EXTREMELY LONG INTERVALS

Figure 4 shows the variation in the running time on each street as the green interval length on Constitution Avenue is varied while the green and amber interval on Seventeenth Street remains constant at 30 seconds. The average vehicle time on Constitution Avenue becomes less as the interval length is extended up to about 40 seconds, after which the rate of decrease in running time becomes increasingly less. Meanwhile the time has been increasing for the vehicles using Seventeenth Street, with the result that above a 40-second interval on Constitution Avenue, the time for the average vehicle begins to increase, even though the more heavily traveled street is the one favored by the control. Figure 6 shows accumulated traffic during a long light interval.

Figure 5 shows the effect of increasing the light interval on the lightly traveled street, while that on the heavily traveled street remains constant. Here the effect noticed in figure 4 is more marked. While the time of the average vehicle on Seventeenth Street decreases but slightly through the longer interval lengths, the time per vehicle on the heavily traveled street mounts very rapidly, and necessarily results in a very

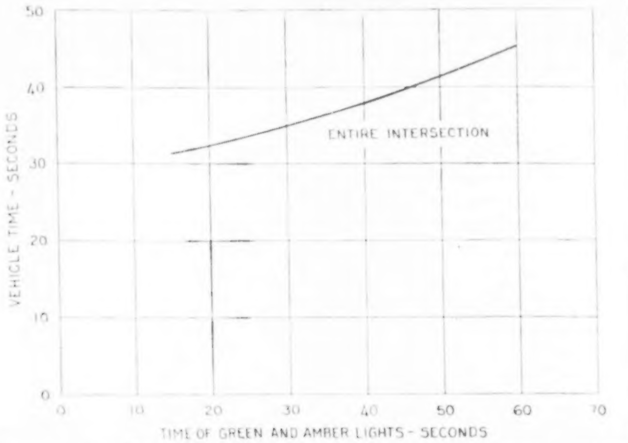

FIGURE 3.—RELATION BETWEEN LIGHT INTERVAL (SAME INTERVAL ON BOTH STREETS) AND AVERAGE TIME OF PASSAGE FOR BOTH STREETS.

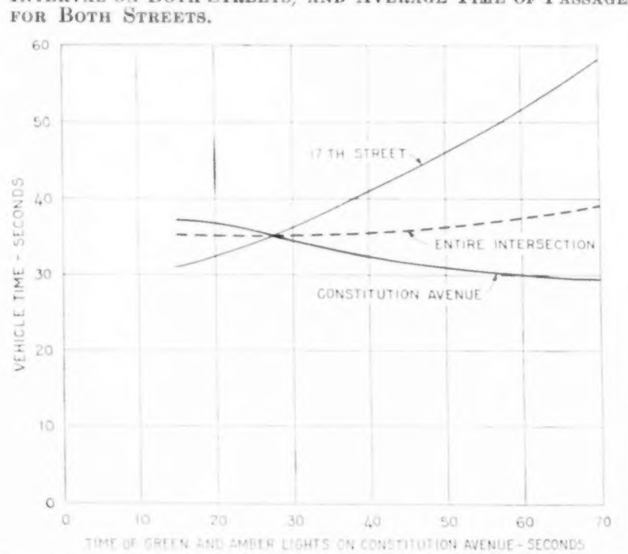

FIGURE 4.—EFFECT ON TIME OF PASSAGE OF VARYING LIGHT INTERVAL ON CONSTITUTION AVENUE WITH LIGHT INTERVAL ON SEVENTEENTH STREET KEPT CONSTANT AT 30 SECONDS.

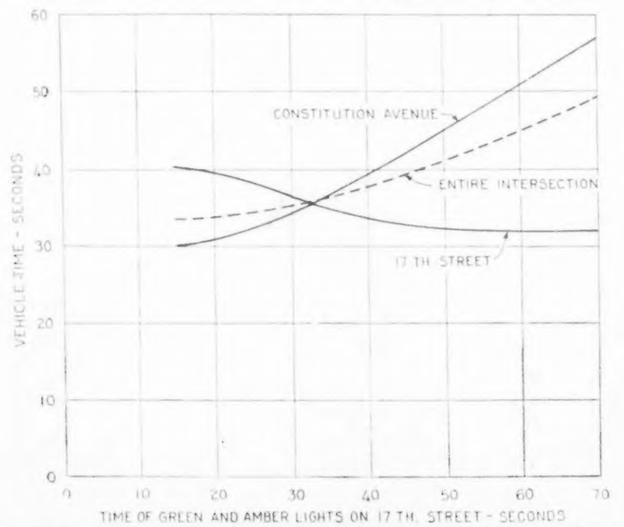

FIGURE 5.—EFFECT ON TIME OF PASSAGE OF VARYING LIGHT INTERVAL ON SEVENTEENTH STREET WITH LIGHT INTERVAL ON CONSTITUTION AVENUE KEPT CONSTANT AT 30 SECONDS.

rapid increase in the average time per vehicle for the entire intersection, when the times are weighted according to the volume on each street

These curves show very definitely that there is no advantage in favoring the heavily traveled street with extremely long intervals. When, following the appearance of the green light, the waiting vehicles have been cleared out and the retarding effect of the stopped vehicles on those immediately following them has disappeared, the flow of traffic through the intersection becomes the uninterrupted normal flow on the street. Further maintaining of the green interval does not result in a material saving of time to vehicles on this street, while the aggregate delay to those vehicles waiting on the other street is mounting more and more rapidly.

That unduly long cycle lengths are a hindrance to the free flow of traffic cannot be too strongly emphasized. Table 2 summarizes for easier comparison certain figures from table 1.

TABLE 2.—*Effect of cycle length on time of vehicle passage through zone of influence*

Green and amber interval		Cycle	Ratio, Constitution Avenue to Seventeenth Street	Average time per vehicle
Constitution Avenue	Seventeenth Street			
Seconds	*Seconds*	*Seconds*		*Seconds*
15	15	30	1 to 1	31.5
60	60	120	1 to 1	45.4
30	70	100	3 to 7	48.6
30	15	45	2 to 1	33.5
15	30	45	1 to 2	34.9
60	30	90	2 to 1	37.1

Table 2 reveals that the fastest movement under fixed time is attained with a setting of 15 seconds on each street, and that the slowest movement is when the control is set at 70 seconds on Seventeenth Street and 30 seconds on Constitution Avenue. This time, however, is but little higher than that for an interval of 60 seconds on each street. The 60—60 setting is at one extreme, while the 15—15 is at the other; the interval ratio is the same but the passage times are the lowest and practically the highest, respectively

With a signal setting of 30 seconds on Constitution Avenue and 15 seconds on Seventeenth Street, the time per vehicle is 33.5 seconds. Reversing the timing conditions on the two streets permits the average vehicle to traverse the zone of influence in 34.9 seconds, an increase of 1.4 seconds per vehicle. Using the same ratio but with a setting of 60 seconds on Constitution Avenue and 30 seconds on Seventeenth Street, the average vehicle time is 37.1 seconds, an increase of 3.6 seconds over the 30—15 setting. Lengthening the cycle in this case produced a greater increase in the time per vehicle than reversing the interval on the two streets while retaining the short cycle. At this intersection, it was more important that the cycle be kept short than that the time within the cycle be correctly proportioned. It is understood, of course, that this is not a general statement to include all conditions. Obviously it cannot be said that with congested traffic, the proportioning is immaterial, but it is strongly emphasized that under any conditions the cycle must be kept as short as practicable.

FIGURE 6.—LONG LIGHT INTERVALS UNDER FIXED CONTROL RESULTED IN WAITING LINES AND HIGH AVERAGE VEHICLE TIME.

FLEXIBLE CONTROLS PRODUCE RAPID VEHICLE MOVEMENT

The study of each control setting covered a period of at least 2 hours. This was considered satisfactory for the fixed times, since the movement was very regular, but more study was devoted to the flexible control methods to insure that no special condition might influence the flow of traffic, which by nature of the control would be somewhat variable. Accordingly, studies of officer control included some 7,200 vehicles, those made without control covered approximately 11,300 vehicles, and those under traffic-actuated control covered over 20,000 vehicles. Of the three flexible methods, operation without control produced the fastest movement, officer control produced the next fastest, and the traffic-actuated resulted in the slowest movement of the three. All three, however, produced a faster movement than any of the fixed-time controls with the exception of the 15–15 setting.

No-control offers the highest degree of flexibility of movement possible, since vehicles from a number o entering ways may be in the intersection at one time. There is, of course, a limit to the volume which an uncontrolled intersection may handle, but this limit was above the range of these observations. During the study rates of over 1,000 vehicles per hour for 15-minute periods in one direction on Constitution Avenue and of over 600 per hour on Seventeenth Street in one direction were recorded. On a per lane basis this would be over 300 per hour per lane for each direction.

The maximum rate for the entire intersection recorded for any one 15-minute period was 2,260 vehicles, divided as follows: Constitution Avenue west-bound 740, east-bound 710; Seventeenth Street north-bound 430, south-bound 380. On a per lane basis these figures become (approximately) 250, 240, 220, and 190 vehicles per hour. Assuming that these figures per lane can be applied to a simple 2-lane intersection, the volume would be then 900 vehicles per hour, with 55 percent on the heavier street. For a 4-lane intersection, these average figures per lane represent an hourly rate of 1,800 vehicles per hour. Such a comparison must be considered as merely an indication, however, since the operating characteristics of a 2-lane or of a 4-lane intersection might be quite different from those of this 6-lane and 4-lane intersection.

During the studies no accident or even near-accident was noted. Toward the late afternoon, when the traffic began increasing, free movement became more difficult and some confusion was apparent. During this period of heavier traffic the vehicle time did not show any marked increase, but it was obvious that a further increase in traffic would increase the confusion to the point of congestion. The vehicle time for the no-control method was considerably less than that for officer control, the next fastest, which appears to be due to the small number of stopped cars. The shortest light control, and the most efficient officer control must stop some vehicles while under no-control almost all vehicles keep moving. Vehicle movement under the traffic conditions studied here, even with the necessary slowing down, is bound to be faster than any sort of regimented movement.

AUTOMATIC TRAFFIC LIGHT ADAPTS CONTROL TO CHANGING CONDITIONS

The officer assigned to direct traffic during this study was exceptionally able and active, and while no doubt his efficiency was increased by his knowledge that the vehicles under his direction were being timed, he would unquestionably direct traffic in a highly efficient manner regardless of scrutiny. He used a semaphore, common to Washington, for indicating the movements, and compelled observance of his signals by vigorous use of his whistle. The longest tour of duty was approximately 2 hours, but he believed that with opportunity for a short rest period at about 2-hour intervals he could maintain this same efficiency throughout an entire day. These studies may not be typical of what an average officer does, but they show what an efficient officer can do. The time per vehicle was 3.6 seconds more than that under no-control, but was 1.6 seconds per vehicle less than the fastest light-control method.

The traffic-actuated control is listed fourth in order of time per vehicle, following the 15–15 setting of the fixed time, but the times of the two are practically identical, 31.5 seconds for the fixed time control and 31.6 seconds for vehicle-actuated light control. The 15–15 setting was entirely satisfactory for the volume of traffic present. It is doubtful if this short cycle would be effective in very heavy traffic, due to the tendency of vehicles to run through the amber and into the red interval under such conditions. Such action was noticeable for the extremely short cycle lengths, even with the moderately heavy traffic encountered during these observations. With an impatient rush-hour traffic such disregard of the signal would result in dangerous confusion.

It is emphasized again that it is not intended to prove by this study that any one type of control is superior to all others under a variety of conditions. The purpose is to find what specific conclusion can be reached from a study under fixed conditions except for cycle arrangement. The fact that one fixed-time cycle shows a time per vehicle of slightly less than that for the traffic-actuated control under the same condi-

tions should not be considered so significant as the fact that the shortest fixed-time cycle shows the least delay of all the fixed-time cycles. The most important feature of traffic-actuated control is its extreme flexibility, and the automatic adaptation to changing conditions. It is significant that this flexible control automatically adjusted itself to practically the same efficiency as that of the fixed-time control best adapted to the conditions existing during the hours studied at this particular location. In addition, it was always ready to control traffic of a different pattern with equal efficiency. No intersection operates under the same traffic conditions from day to day, and but few from hour to hour.

OPERATION OF AUTOMATIC CONTROL DESCRIBED

A brief description of the operation of this traffic-actuated control will aid in understanding the significance of the figures in following analyses. The signals themselves are the same as in any other light control, but instead of being actuated by a cam or other constant-speed mechanism, the changes are actuated by the vehicles passing through the intersection. The interval lengths are determined by the vehicles approaching the intersection, which results in continually varying cycle lengths. The particular device used is ingenious in conception and simple in operation, the various phases of the signal being initiated by the functioning of electric condensers in the control mechanism.

Assume that traffic is flowing on street A, and no traffic is waiting on street B. This traffic will continue to flow without interruption until the arrival of a car on street B requires the right-of-way for that street. On crossing a detector placed at some distance from the intersection (see fig. 1), the car on street B imparts an impulse to the control mechanism, after which street B receives the green signal by virtue of one of two reasons. First, a gap may occur in the traffic on street A. If this gap in traffic is of such length that no vehicle crosses the detector on street A for a period equal to the "vehicle interval", the length of which may be varied in the control mechanism, the right-of-way is given to street B immediately. If no such gap occurs in the traffic on street A, the right-of-way will revert to street B after a certain time called the "maximum interval", which also may be varied in the control mechanism.

One other feature of importance is the "initial interval." This period is to allow stopped vehicles waiting for the signal change a greater time to clear the intersection than is necessary for vehicles crossing the detector at a normal driving speed.

The efficiency of this equipment depends to a considerable degree on the setting of the various interval lengths. During this study the settings were as follows: Vehicle interval on each street, 5 seconds (the lowest available); initial interval on each street, 7 seconds; maximum interval on Constitution Avenue, 30 seconds, which allowed a maximum time of 30 plus the initial interval, or 37 seconds; and the maximum interval on Seventeenth Street, 35 seconds, or a maximum time of 42 seconds. The longer maximum on Seventeenth Street was necessitated by the rush of traffic on this street for a short period just before 4:30 p.m., before traffic on Constitution Avenue had shown a marked increase. These settings were those used by the Park Police, and are believed to be the most satisfactory for this location. Typical conditions under traffic-actuated control are illustrated in figure 7.

Officer control and traffic-actuated control are much alike in their operating characteristics. Analysis of these two types offers interesting comparisons, and throws more light on the result of increasing the interval and cycle lengths. Table 3 summarizes certain features of the flexible control methods.

TABLE 3.—*Comparison of flexible control methods*

Control	Average cycle				Average vehicle time	Vehicle time for same cycle with fixed light control	Benefit of flexibility	
	Constitution Avenue	Seventeenth Street	Ratio	Total			Time	Percent
	Seconds	*Seconds*	*Seconds*	*Seconds*	*Seconds*	*Seconds*	*Seconds*	
Officer	26.8	18.0	1.5-1	44.8	29.9	32.5	2.6	8.0
Vehicle-actuated light	23.4	17.1	1.4-1	40.5	31.6	32.1	0.5	1.5

OFFICER CONTROL AND TRAFFIC-ACTUATED CONTROL COMPARED

The cycle lengths of table 3 are the averages for all studies on these control methods, and the vehicle times for fixed-time cycles of the same interval were computed with equation 1. Two factors are important in this table. First, each flexible control method shows a slight advantage over what might be expected from fixed-time control of the same time intervals. This does not mean that flexible control results in faster movement than fixed control of some other interval length (see results of 15–15 timing in table 2), but it shows the advantage of flexible control over a comparable fixed-time setting. Again it must be remembered that the

FIGURE 7.—(UPPER) CONDITION UNDER WHICH TRAFFIC ACTUATED CONTROL IS EFFECTIVE AND (LOWER) TYPE OF TRAFFIC WHICH WILL HOLD THE GREEN LIGHT UNLESS "VEHICLE INTERVAL" IS SHORT AND RESULT IN INCREASED AVERAGE VEHICLE TIME.

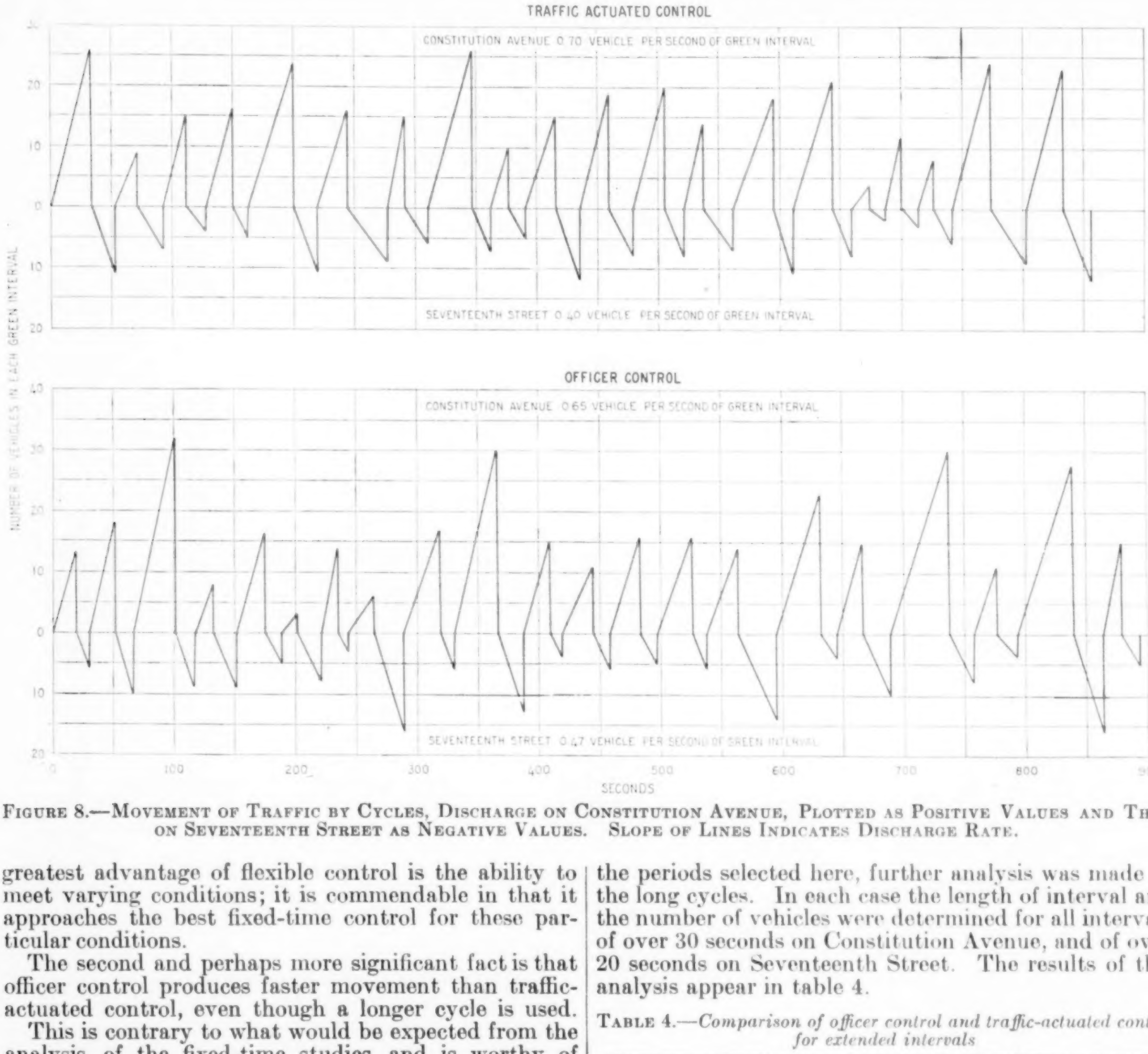

FIGURE 8.—MOVEMENT OF TRAFFIC BY CYCLES, DISCHARGE ON CONSTITUTION AVENUE, PLOTTED AS POSITIVE VALUES AND THAT ON SEVENTEENTH STREET AS NEGATIVE VALUES. SLOPE OF LINES INDICATES DISCHARGE RATE.

greatest advantage of flexible control is the ability to meet varying conditions; it is commendable in that it approaches the best fixed-time control for these particular conditions.

The second and perhaps more significant fact is that officer control produces faster movement than traffic-actuated control, even though a longer cycle is used.

This is contrary to what would be expected from the analysis of the fixed-time studies and is worthy of further analysis. Table 3 shows that the officer divided the time between Constitution Avenue and Seventeenth Street in the ratio of 1.5 to 1, whereas the traffic-actuated control gave Constitution Avenue only 1.4 times as much time as Seventeenth Street received. With cycle lengths as near alike as these, the one which allowed the light-traffic street the smaller proportion of the cycle should show the lowest weighted average time per vehicle. Further information with respect to the details of these methods may be obtained from figure 8, which shows the time interval variation during random 15-minute periods for the flexible control methods and the corresponding discharge rates.

In preparing figure 8 periods were chosen in which the average time interval closely approximated the average time interval for the entire study of each method. The slope of the lines shows that the time interval generally varied with the number of vehicles. It is apparent that where the interval length on Seventeenth Street increases, the number of vehicles appears to follow this increase more closely in the case of the officer control than for the traffic-actuated control. Accordingly, for the periods selected here, further analysis was made of the long cycles. In each case the length of interval and the number of vehicles were determined for all intervals of over 30 seconds on Constitution Avenue, and of over 20 seconds on Seventeenth Street. The results of this analysis appear in table 4.

TABLE 4.—*Comparison of officer control and traffic-actuated control for extended intervals*

	Officer control	Traffic-actuated control
Constitution Avenue:		
Average vehicles per second	0.65	0.70
Vehicles per second in long intervals (over 30 seconds)	.69	.67
Difference in vehicles per second between average conditions and long intervals	+.04	−.03
Above difference as a percentage	+6.2	−4.3
Seventeenth Street:		
Average vehicles per second	.47	.40
Vehicles per second in long intervals (over 20 seconds)	.52	.38
Difference in vehicles per second between average conditions and long intervals	+.05	−.02
Above difference as a percentage	+10.6	−5.0

Table 4 shows that the officer control not only was relatively more efficient in the long cycles than was the traffic-actuated control but was actually more efficient in the longer cycles than in the shorter ones. This indicates that the vehicle-actuated control held the right of way too long on one street for scattering traffic, whereas the officer did not give a long cycle unless the traffic demanded it. This is a further reason for the apparent inconsistency between officer and traffic-actuated control, where the method showing the longer

average cycle showed the faster movement. From this two conclusions may be deduced. (1) The traffic-actuated control did not have quite the flexibility of officer-control, and (2) the officer might have been more efficient had he been able to maintain a shorter average cycle. The fact that the use of the longer cycles was more efficient than that of the shorter ones indicates usage of over average intervals only when traffic demanded it, and that short and average cycles could have been still shorter.

SHORT "VEHICLE INTERVAL" DESIRABLE IN AUTOMATIC CONTROL

Since the operation of the traffic-actuated control is dependent entirely on the spacing of traffic, it is of interest to examine the flow of traffic on the two streets. Constitution Avenue, during the hours studied, carries approximately 1,390 vehicles per hour, and Seventeenth Street carries about 670. This means that at evenly spaced intervals vehicles would arrive on Constitution Avenue about every 2.6 seconds, and on Seventeenth Street every 5.4 seconds. Of course vehicles do not arrive so regularly, and it is because of the grouping tendency that traffic-actuated control is effective. However, on a city street speeds are more nearly uniform than on an open highway, and with closely spaced intersections, traffic may enter or leave a street at frequent intervals. For these reasons, with the relatively heavy volume recorded at this intersection, the flow was more nearly uniform, or continuous, than grouped.

On Constitution Avenue, for example, vehicle-actuated control, operating with a vehicle interval of 5 seconds, permits the clearing out of the stopped cars, and then may hold the right of way while the traffic on the street flows at only its normal frequency. This is not so serious on the heavily traveled street as on the one with lighter traffic, as was brought out in figures 4 and 5, but it does work to the disadvantage of this type of control.

The two detectors on a street are connected to the dispatcher in parallel with one another. An impulse on one, followed by an impulse on the other 4.9 seconds later, followed by another impulse on the first detector at another 4.9-second interval could hold the right of way with a spacing of vehicles in both directions of practically 10 seconds. While this extreme case is seldom found, it was frequently noted that the right of way was held for only a scattering of cars. It has been shown that it is wasteful of time to permit the traffic on even the more important street to flow any considerable length of time after the waiting vehicles have cleared the intersection. A control, to be the most effective, should not cause waiting for a gap in the normal flow of traffic on one street to permit the cross traffic to flow, but should revert to the other street as soon as the traffic on the first street becomes normal provided there is not too great a disparity in traffic on the two streets.

A control mechanism of the type used should be arranged so as to be set for a vehicle interval as low as 3 or even 2 seconds for traffic such as was observed. Five seconds was the shortest time available for the vehicle interval in this particular instrument, and no observations with shorter intervals could be made. It is reported, however, that a reduction of from 8 to 5 seconds in one particular case (Providence, R.I.) resulted in a material improvement in the flow of traffic, and it is believed that reduction of from 5 to 3 seconds, would result in reduced delay at this intersection.

VEHICLE DELAY DETERMINED

In the foregoing discussion of efficiency it may have been noted that comparisons were always made of the vehicle time. This was what was actually measured, and this offered the fairest comparison of efficiency. However, what is more important to certain interests is the delay to traffic caused by various types of control. Having found the total elapsed time for the average vehicle to traverse the 600 feet included in this intersection zone, to find the delay it is necessary only to subtract from the elapsed time the time required to traverse the distance at normal driving speed. In the District of Columbia the legal speed limit is 22 miles per hour, and at this speed a vehicle requires 18.5 seconds to travel 600 feet. Assuming 22 miles per hour as the normal driving speed on the streets approaching this intersection, the delay under various conditions is as shown in table 5.

TABLE 5.—*Delay under various control methods based on assumption of 22 miles per hour as normal driving speed*

Control method	Vehicle time	Vehicle time corresponding to normal speed	Delay	Vehicles per hour	Delay per hour (car minutes)
	Seconds	*Seconds*	*Seconds*		
No control	26.3	18.5	7.8	2,000	260
Best method of control recorded	29.9	18.5	11.4	2,000	380
60-60	45.4	18.5	26.9	2,000	900

The figures in table 5 are for normal daytime traffic only. Studies made during certain rush hours, indicate that the time of an average vehicle in rush hours could not be less than 50 seconds, under efficient control. Using this somewhat arbitrary, but conservative figure, the delay per vehicle during the rush hour, assuming the same driving speeds as during the lighter midday traffic, must amount to a minimum of 30 seconds per vehicle, and for the 3,500 vehicles recorded from 4:15 to 5:15 p.m., causes a delay of 1,750 car minutes per rush hour. Under the best control methods at this particular intersection, for a 10-hour day, including two rush hours, the minimum delay which can be expected is as follows:

8 normal hours,	8×380	$= 3{,}040$ car-minutes
2 rush hours	$2 \times 1{,}750$	$= 3{,}500$ car-minutes
		6,540 car-minutes

It is not practicable to fix a definite value for the economic loss incurred by traffic delays. Various agencies have advanced theories applying to particular cases which no doubt have definite merit, but which cannot be applied generally. Costs have been computed from such basic assumptions as the amount of gasoline consumed while waiting in traffic, and the increased wear on vehicles in acceleration and deceleration, and also from such arbitrary assumptions as the value of the time lost by the occupants of even purely pleasure vehicles. These range from extremely low figures to values as high as 5 cents per car-minute, obviously fantastic for the average case. For these reasons no value of time lost is assumed to be applicable to general conditions, but it is of interest to investigate how much this loss might amount to under various assumed values of the cost of delay. Figures for time lost in a 10-hour

day (8 a.m. to 6 p.m.) appear in table 6. It will be noted that these figures are based on the most efficient control. If a similar intersection were operated under poor control, the delay would be much greater.

An interesting feature with respect to delay is its distribution through the day. Using the 10-hour day previously referred to, it may be seen that of the 6,540 car-minutes delay, 3,500 car-minutes, or over half the delay, was incurred during the two rush hours. Any reduction in delay during these periods will have a marked effect on the time loss for the whole day.

TABLE 6.—*Economic loss incurred in a 10-hour day based on assumed values per car-minute*

Assumed cost per car-minute	Delay per day (car-minute)	Per day	Per year (300 days)
Cents			
½	6,500	$32.50	$9,750
1	6,500	65.00	19,500
1½	6,500	97.50	29,250
2	6,500	130.00	39,000

SUMMARY OF CONCLUSIONS

(1) For the traffic volume observed in this study (about 2,000 vehicles per hour) operation of the intersection without control incurred the least delay to traffic. Of all the control methods, officer control permitted the fastest movement of traffic, closely followed by the shortest fixed-time control, and traffic-actuated control.

(2) Under fixed-time control, a very marked increase in delay resulted from lengthening the cycle. For certain of the short cycles with unequal intervals on the two streets, reversing the proportioning of the cycle had less effect on the time of the average vehicle than did retaining the same proportioning but doubling the cycle length.

(3) The flexible control methods showed efficiency equal to or better than the most efficient fixed-time control, but it is believed that both the officer control and traffic-actuated control could be more efficient than indicated here.

(4) During the course of a 10-hour day from 8 a.m. to 6 p.m. as much delay is incurred during 2 hours of peak traffic as during the remaining 8 hours.

APPENDIX.—METHODS OF SURVEY AND ANALYSIS

It is believed that a description of the methods of collecting and analyzing the information presented in this report will be of interest, since as far as is known, few, if any such detailed analyses of vehicular movement have been attempted. As previously noted, delay to traffic at an intersection includes time lost in waiting, decelerating and accelerating, or in driving at a low speed in anticipation of a signal change. While for comparative purposes the determination of but one of these factors may be sufficient, if it is desired to determine the absolute time loss all the factors must be considered. The distance within which delay occurs is defined as the zone of influence of the intersection, and varies with local conditions. The difference in the average time required to traverse this zone of influence and the time required to traverse the same distance at a normal driving speed represents the delay caused by the intersection.

ARRANGEMENT OF OBSERVERS AND APPARATUS DESCRIBED

Since the actual timing of a particular vehicle through the intersection would be difficult, and because, were this feasible, only a small sample of traffic could be timed a method was developed using a graphic time recorder which permitted the timing of all vehicles using the intersection. The instrument (fig. 9) consisted of a strip chart operated by clockwork at a known speed, under a number of pens, electrically operated by the closing of various circuits. Any pen could be actuated by a telegraph key at any point to which it was convenient to extend wires. It was possible to station an observer at a predetermined point just outside the zone of influence who recorded each vehicle approaching the intersection as it passed his post. Other observers, each equipped with a key in series with a different pen, then recorded these same vehicles as they left the intersection zone, one observer being stationed on each of the three streets by which the vehicle might leave the intersection.

In this study the observers (fig. 10) were located 300 feet from the intersection. An "incoming" observer on each street recorded all vehicles entering the intersection zone as they passed his post, and accounted by special notation for all abnormal movements, such as parking, between his post and the intersection. To record the outgoing traffic, each "outgoing" observer, one for each street, was equipped with three keys, one for each of the three streets from which the outgoing vehicles might have entered the intersection. It was

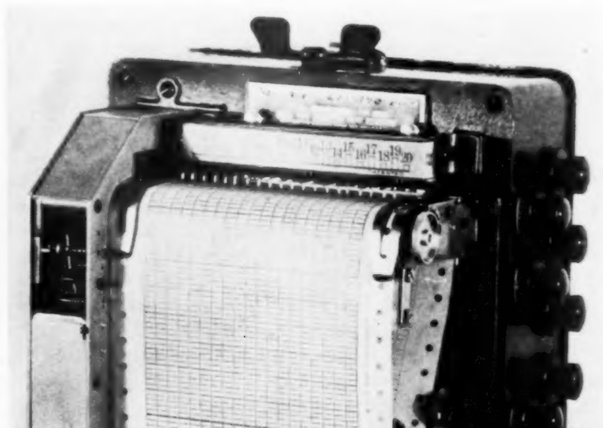

FIGURE 9.—THE TIME-RECORDING MACHINE.

FIGURE 10.—RECORDERS OF INCOMING AND OUTGOING TRAFFIC AND TRUCK CARRYING RECORDING APPARATUS.

necessary for this observer to classify the vehicles as they left the intersection, according to whether they came straight through or from the right or left, and record them with the proper key when they passed his post. This recording was simplified somewhat by the traffic control, for except for unusually fast or unusually slow vehicles near the beginning or end of the green interval on either street, the vehicles during one interval were all "through" and during the other interval were all from either "left" or "right", and it was seldom that the three classifications need be noted simultaneously.

Two observers and 4 keys at each post required 8 observers and 16 keys for a complete record of the operation of all traffic using the intersection. The time recorder was equipped with 20 pens, which permitted the use of four for other purposes. A relay in the light-control box (fig. 11) actuated a pen and automatically recorded the cycle of the signal light. Two pens were used to record all vehicles as they passed the crosswalks on entering the intersection, and the remaining pen was kept ready for emergency, to provide for the occasional failure of one of the pens to function properly.

ANALYSIS OF RECORD CHARTS PRODUCES ACCURATE DATA ON VEHICLE TIME

The time required for the average vehicle to pass through the intersection was determined as follows: Assume vehicles approaching the intersection on a given street are recorded as they enter the zone of influence at a, b, c, d, and e seconds after any selected

FIGURE 11.—TRAFFIC CONTROL BOX.

zero point on the chart. These vehicles are recorded on the various "outgoing" pens at times a′, b′, c′, d′, and e′ seconds after this same zero point. The time for each of the vehicles to traverse the intersection is $(a'-a)$, $(b'-b)$, $(c'-c)$, $(d'-d)$, and $(e'-e)$, and the total time for all vehicles is the sum of these expressions, or $(a'+b'+c'+d'+e')-(a+b+c+d+e)$. Dividing by the number of vehicles gives the average time per vehicle.

Whether one vehicle of this group passes another is immaterial. Assume the first vehicle passed the second and third. The times of the individual vehicles would then become $(a'-b)$, $(b'-c)$, $(c'-a)$, $(d'-d)$, and $(e'-e)$ and as before, the total time would be $(a'+b'+c'+d'+e')-(b+c+a+d+e)$. In using this method it is essential that the records on the "outgoing" and "incoming" pens, respectively cover the same group of vehicles. For each period of study the "incoming" and "outgoing" records must begin with the same vehicle and end with the same vehicle. Every vehicle recorded as "incoming" must be recorded as "outgoing" at some point, in order that the total "outgoing" vehicles equal the "incoming" total. Having ascertained that the "incoming" and "outgoing" records start with the same vehicle, and also stop with the same vehicle, the movement of vehicles within this group relative to one another is immaterial, and it is only necessary to account for all vehicles entering and leaving, and to discount by special notation all unusual movements such as parking, stopping for other than traffic delays, entering or leaving the zone of influence at a point other than that at which the observers are stationed.

Various methods may be used to indicate the vehicle with which the record should begin or end. At this intersection each of the four directions was considered in order and the observers were signaled from the intersection as to the proper vehicle, usually the first after a gap in the traffic, with which to start recording. Often the intersection was entirely clear of traffic entering from a particular direction, and this could be noted on the chart by the recorder by special manipulation of the key. Such a "break" is helpful in analysis of the chart, for if no vehicles are in the zone of influence at any given time, the succeeding records must necessarily begin with the proper vehicle.

For ease in analysis the circuits were so arranged that for the "incoming" record appearing on pen 1, the "outgoing" records for the through, right and left movements appeared on pens 2, 3, and 4, respectively. Similar groups of four pens accounted for the movement on the other streets. The record on each chart covered from 2 to 3 hours. To facilitate analysis and to investigate the short time fluctuation of traffic, the record was broken up into periods approximately 15 minutes in length. Experience showed that shorter periods often gave disproportionate results, and much longer periods made analysis of the charts more difficult.

Charts were examined carefully and all special notations made by the recorders during the study properly accounted for. The "outgoing" record on each street was checked against the "incoming" record, which made mistakes immediately apparent. Errors in recording heavy traffic are bound to occur, but due to the character and training of the observers mistakes were not frequent. The largest portion of mistakes could be traced to the "outgoing" recorder using the wrong key, since vehicles were classified at the intersection but were not recorded until they passed the observers post. For example, should a left turn be recorded as a right turn, the "outgoing" record from one street would show a surplus of one car, which would correspond to a deficit in the "outgoing" record from another street. Such errors could be recognized and a correction made on the record chart. Other errors could be isolated within a short period by means of the recorders "breaks," and correction made. With the "incoming" and "outgoing" records in agreement, the average time per vehicle was computed using the method outlined above.

SIMPLER METHODS REQUIRED FOR GENERAL USE

The purpose of this study was to determine the effect of the variation in control methods under conditions of traffic as nearly constant as possible. After computation of the average running time for each 15-minute period, this time was plotted against the volume for the particular period for each control method, as a safeguard against including times influenced by any external factors. While certain periods showed rates of flow deviating somewhat from the average, there were few in which there was possibility of tracing any change in running time to the variation in volume, and these were not considered in the final analysis.

Investigation was made of the effect of left turns. It was found that left turns which, on Constitution Avenue, the heavier traveled street, ranged from 5.6 percent to 18.0 percent of the total traffic, and on Seventeenth Street ranged from 20.0 percent to 42.8 percent, had no apparent effect on the average running time, within the range of volumes observed. While no doubt left turns in congested traffic will have a marked effect on traffic delays, no such effect was noted in this moderately heavy traffic. Pedestrian traffic was negligible during the hours included in these observations.

The methods used permitted the accurate timing and detailed analysis of the speed of traffic. Probably no more accurate or inclusive information could be obtained with methods now available to traffic investigators. The question arises as to whether such a detailed analysis is necessary. Obviously a method similar to this is essential if all the delay to traffic is to be accurately analyzed, but there may be some question as to the necessity of going to such extremes in accuracy and detail to obtain satisfactory information at an ordinary intersection. Such a study requires, if the traffic is heavy, a minimum of 8 recorders, a supervisor and a time-recorder operator. Lighter traffic may permit the reduction of the recorders to 6, or possibly to 4, or for certain types of studies the intersection might be analyzed in one direction at a time, but whatever the arrangement of personnel, there is required a laborious and somewhat complicated laying out of wires and assembling of equipment. For a study as detailed as the one made a light truck was essential, and this together with the time recorder and its accessories represents a considerable investment. More than average accuracy and experience on the part of the recorders is required.

Obviously, this method of analysis is not adapted to widespread use. It is hoped that these studies will provide material which will point to simpler and more generally applicable methods of analysis which will at least provide information sufficiently accurate for comparative purposes. It may be possible to determine factors, which can be applied to less extensive data than were collected and thus provide satisfactory figures on delay.

AN IMPROVED METHOD OF MEASURING SPEED OF TRAFFIC

Reported by E. H. HOLMES and LAWRENCE S. TUTTLE, Assistant Highway Economists, United States Bureau of Public Roads

Subsequent to the studies described in the preceding papers in this issue of Public Roads, there has been a further development of field methods used in the determination of vehicle time loss. The method used in the New Jersey Viaduct study consisted of recording the licenses and the times of passage of vehicles at both ends of the route under consideration. Since the length of the route was about 4 miles, recording of time to the nearest minute was sufficiently precise. A large proportion of the vehicles were recorded in this way and the average travel time was determined from the travel time of the individual vehicles.

In the method used in the Constitution Avenue and Seventeenth Street study the travel time per vehicle was not determined by averaging the time for individual vehicles. Instead the average time was obtained by dividing the aggregate time for all vehicles by the number of vehicles. Here the distance was but a few hundred feet rather than several miles, and so the time of passage of the vehicles had to be noted precisely. The required precision was obtained with the electric time recorder, which permitted timing to the nearest second. While this type of study was very precise, its accuracy was dependent on the "incoming" and "outgoing" records being in exact agreement.

The two methods, while entirely satisfactory in each special case, are limited in their application. The first method can be used only where the distance over which the vehicles are to be timed is great enough that recording to the nearest minute, or possibly to the nearest half minute, will give the elapsed time with sufficient precision. This method is advisable only when most of the traffic passes both observation points, for otherwise the sample is small. Such diversions or entrances of traffic may be accounted for, however, by the use of additional observers at the diversion points. The second method is useful only over a short distance where both ends of the section of street or highway are readily visible from a selected point, which sets a practical limit of about 1,000 feet to the length of the section. Difficulty is encountered if there is a considerable amount of stopping or parking within the section studied, or if vehicles enter or leave at points other than those at which the observers are located. Stores, filling stations, or building entrances make such a study very difficult, while another street intersection within the "zone of influence" of the intersection being studied excludes this type of study entirely.

Observations at intersections in business sections recently investigated were so complicated by business stops and by the long lines of vehicles awaiting signal changes during rush-hour traffic that neither method was suitable. However, a combination of the two methods proved successful.

Under this system, the licenses are recorded as the vehicles enter and leave the "zone of influence" of the intersection, and the time of passage of each vehicle is noted on the time-recorder chart by the closing of a circuit with a telegraph key as in the regular intersection study. This type of recording requires two observers at each post for each direction. One reads aloud the license number and simultaneously records the time of passage of the vehicle with the telegraph key. The other writes on a ruled sheet the number read by the first observer.

In order to correlate the time record appearing on the strip-chart with the license record shown on sheets, it is necessary for the observers to designate at frequent intervals a certain car as a "check" vehicle. The license number of this vehicle is checked or otherwise noted on the sheet, and its time of passage indicated on the time-record chart by a special manipulation of the telegraph key. Usually it was found convenient to check every tenth vehicle in this way, with distinctive notations for the fiftieth and hundredth vehicles. To facilitate this correlation of the records, the sheets used by the observers were previously ruled, and the tens, fifties, and hundreds indicated on them. Recording of these "check" vehicles was not difficult, since the recording observer, after recording nine numbers, would announce to the "reading" observer whose eyes were on the traffic, that the following vehicle would be the tenth.

If the distance over which the record is being made is short, as at an intersection, the last 3 digits of licenses will be sufficient for identification of vehicles. Using this 3-digit recording, 2 observers can record as many as 800 vehicles per hour with little difficulty.

Analysis of the information obtained requires first matching the numbers shown on the "incoming" sheets with those shown on the "outgoing" sheets and eliminating all those which do not appear on both sheets within a reasonable elapsed time. Then, since the time record on the chart is correlated with the license record on the sheets, these same vehicles may be eliminated from the chart. With the vehicles not matching removed from the record, the aggregate time for all vehicles is obtained by the summation of the "incoming" and "outgoing" times, as described in the preceding paper, and the average trip time found from this figure.

In addition to providing an accurate record of "incoming" and "outgoing" times from which an aggregate time for all vehicles may be found, this type of study, because of the possibility of identification of particular vehicles, permits a much more detailed analysis than is possible with the regular intersection analysis. For instance, it is very easy to time separately right and left turns, or to make a complete analysis of the movement of vehicles through multiple intersections.

Use of this method is not confined to intersections. It is ideally adapted to analysis of traffic on open highways. It is possible to determine the average speed maintained over a given section of highway and how the speeds of the individual vehicles vary from the average speed. The effect of changes in traffic volume on average speed and freedom of movement can be studied. Determinations may also be made of the capacity of traffic lanes under ideal conditions, and how their capacity may be affected by grades, curves, and road widths.

To conduct such a study on the highway it is necessary only to station observers at the two or more critical points between which information is desired. The distances which may be included are dependent only on the length of wire which it is practicable to lay out for the study.

By gradual development and combination of proven methods, it is now possible to analyze accurately the movement of traffic over distances up to several miles. Practically every condition of traffic flow may be studied by some combination of the methods described.

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION
AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS I—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM
OUTSIDE OF MUNICIPALITIES

AS OF JANUARY 31,1934

STATE	PUBLIC WORKS FUNDS ASSIGNED FOR CLASS I PROJECTS ON THE FEDERAL AID HIGHWAY SYSTEM	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR NEW CLASS I PROJECTS
		Total cost	Public works funds	Regular Federal aid	Mileage	Estimated total cost	Public works funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	Public works funds allotted	Mileage	
	$	$	$	$		$	$	$			$		$
Alabama	4,185,067					4,441,734.76	2,451,108.12	1,990,626.64	26.3	250.9	592,998.62	58.2	1,140,960.26
Arizona	3,804,731	305,538.61	305,538.61		21.6	3,049,361.87	2,667,079.99		26.9	228.0	182,322.13	3.3	649,790.27
Arkansas	3,374,167	18,339.52	9,849.52	8,490.00	.6	1,398,998.25	1,020,035.88	378,962.37	35.3	56.9	592,933.47	42.6	1,751,345.13
California	7,803,677	92,145.42	74,403.20		1.8	7,562,941.95	5,894,074.97		24.3	227.7	1,131,999.51	43.9	703,199.32
Colorado	3,437,265	500,887.00	500,887.00		33.3	1,482,693.51	1,472,113.16		34.7	68.5	295,795.28	12.0	1,168,469.56
Connecticut	1,404,813					1,230,901.72	1,055,122.78	175,778.94	5.6	24.4	309,548.49	6.3	39,241.73
Delaware	909,544	133,532.30	133,532.30		15.4	742,815.70	742,815.70		21.3	17.4			33,196.00
Florida	2,615,917					2,572,665.70	1,791,781.49	780,274.11	33.5	92.6	555,647.43	18.3	268,488.08
Georgia	5,045,992					1,759,445.32	1,759,445.32		33.6	96.1	1,123,450.05	77.5	2,162,696.63
Idaho	2,243,185	274,499.49	273,270.57		35.5	1,358,904.11	1,345,399.96		43.6	95.1	146,518.90	13.4	477,935.57
Illinois	4,431,348					922,816.03	922,816.03		10.2	21.8	563,855.05	8.2	2,944,676.92
Indiana	4,717,786					1,974,416.80	1,974,416.80		28.7	67.5	1,124,202.64	32.2	1,619,166.56
Iowa	5,027,830	707,037.81	704,400.00		30.0	3,948,094.43	3,719,700.00		30.2	209.8	492,480.00	22.8	111,250.00
Kansas	5,044,802	149,657.30	149,657.30		49.5	3,099,840.41	3,095,879.28		32.6	285.4	1,799,265.42	66.4	
Kentucky	3,608,332	90,579.10	90,579.10		2.9	1,823,231.23	1,823,231.23		33.0	142.1	1,155,509.82	87.9	539,011.85
Louisiana	2,914,295	12,626.07	12,626.07		.4	2,026,345.04	1,519,694.04		22.2	37.0	784,551.81	30.5	597,423.08
Maine	1,684,959					1,161,321.30	1,125,754.35		36.5	35.5	218,070.16	7.4	341,134.49
Maryland	1,782,263					801,143.78	791,495.03		7.1	14.8			990,767.97
Massachusetts	1,101,716	153,936.88	83,952.64	69,984.24	4.2	1,112,362.46	796,702.82	315,659.64	17.8	32.8	112,698.19	.8	108,362.35
Michigan	5,094,491	35,500.00	35,500.00		1.2	2,449,550.00	2,449,550.00		33.5	130.6	2,276,866.00	88.0	332,575.00
Minnesota	5,115,153	1,232,279.59	1,232,279.59		257.2	1,819,309.81	1,819,309.79		30.2	266.3	515,258.72	141.2	1,548,304.90
Mississippi	3,489,337					2,909,936.11	1,564,495.62	1,306,808.55	10.7	145.0	460,775.41	56.7	1,464,065.97
Missouri	6,090,153	318,173.69	219,506.32		20.1	3,319,647.58	3,004,621.74	25,499.64	41.9	105.2	1,546,982.18	56.3	1,319,042.76
Montana	4,463,849	218,002.08	218,002.08		34.0	3,708,805.40	3,435,926.52	192,878.88	31.8	268.5	656,603.46	40.7	153,316.94
Nebraska	3,914,481	381,123.97	255,420.54		144.8	3,799,643.85	2,945,410.14	108,538.00	39.2	176.3	557,688.11	57.3	155,962.21
Nevada	2,909,387	272,235.60	272,235.60		60.3	1,466,705.48	1,466,705.48		22.4	131.4			1,170,445.92
New Hampshire	725,739					545,335.31	539,650.31		28.5	9.2	99,120.09	1.6	86,968.60
New Jersey	3,065,137					1,098,555.56	1,098,555.56		9.3	19.3	845,917.99	10.3	1,120,663.45
New Mexico	2,896,467	1,072,779.31	1,072,779.31		139.0	1,311,063.23	1,311,063.23		2.5	94.3	426,264.11	44.4	86,360.35
New York	10,830,099	117,100.00	117,100.00		3.8	9,197,850.00	8,225,175.00	315,000.00	24.2	201.8	1,858,230.00	29.6	629,594.00
North Carolina	4,761,147	444,700.10	222,350.08	222,350.02	35.1	1,289,338.80	959,681.10	329,657.70	33.7	149.1	1,578,487.71	218.7	2,000,628.11
North Dakota	2,902,224	500,761.09	500,757.58		249.7	861,077.82	861,077.82		10.9	230.6	1,165,294.81	395.6	375,093.79
Ohio	6,968,066	213,370.00	213,370.00		4.8	5,686,265.00	5,568,315.00		34.3	147.5	883,975.00	21.4	302,406.00
Oklahoma	4,608,399	122,702.34	122,702.34		5.1	3,179,499.30	3,179,499.30		36.2	195.8	834,989.24	78.6	471,208.12
Oregon	3,053,448	345,126.66	317,233.16		40.4	2,203,511.26	2,098,973.80	14,616.53	23.0	101.5	484,706.10	37.9	172,535.54
Pennsylvania	5,757,978	12,791.10	12,791.10		.2	3,985,025.14	3,985,025.14		11.6	97.2	1,446,164.14	26.6	313,997.62
Rhode Island	999,354	18,830.63	18,830.63		.5	969,153.21	969,153.21		25.9	20.0	10,468.37		901.79
South Carolina	2,729,583	1,740.69	1,740.69			1,886,219.50	1,883,489.88	2,729.62	26.6	184.4	282,842.64	22.5	561,509.79
South Dakota	3,005,739	871,013.41	865,096.92	5,916.49	145.0	1,101,467.48	1,069,443.19	32,024.29	6.3	177.2	467,166.15	50.2	604,032.74
Tennessee	4,246,309	131,887.64	72,591.00	59,296.64	5.1	2,571,906.04	2,055,185.30	516,720.74	22.9	98.5	1,257,905.72	48.7	860,626.98
Texas	12,122,012	375,515.25	301,232.95		97.5	7,151,369.87	6,072,823.35		23.9	616.3	2,451,598.23	269.9	3,296,357.47
Utah	2,374,205	869,670.21	869,670.21		101.5	1,032,219.87	1,031,824.97		25.3	80.9	300,059.76	12.1	172,650.06
Vermont	931,919	47,983.81	47,983.81		6.2	735,351.85	707,198.60		29.7	34.7			176,736.59
Virginia	3,708,379	150,795.89	133,613.02	17,182.87	10.2	1,586,019.40	1,585,607.09	412.31	31.5	56.1	1,565,216.55	60.1	423,942.34
Washington	3,057,934	202,645.88	202,645.88		13.7	2,105,073.42	2,101,716.60	3,356.82	18.3	75.4	370,607.20	14.9	382,964.32
West Virginia	2,013,405	144,034.00	144,034.00		4.9	1,522,383.88	1,522,383.88		40.5	64.5	261,526.91	2.8	85,460.21
Wisconsin	4,862,441	298,477.25	288,174.42	1,190.00	15.7	2,502,675.31	2,481,175.31	21,500.00	37.6	101.1	434,346.68	37.5	1,658,744.59
Wyoming	2,250,663	576,020.88	488,300.00	60,000.00	108.2	1,529,554.80	1,441,853.00	18,000.00	21.4	308.7	104,382.61	39.0	216,127.39
District of Columbia													
Hawaii	1,683,956	25,988.65	12,994.33	12,994.32	.9	1,328,218.44	1,096,391.33	181,827.36	4.4	27.9	281,437.50	4.0	293,132.84
TOTALS	185,768,083	11,440,029.22	10,597,631.87	457,404.58	1,700.3	117,322,766.49	104,499,947.61	6,710,872.14	26.9	6,319.6	34,587,028.36	2,358.3	36,083,475.16

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION
AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS II—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF JANUARY 31, 1934

STATE	PUBLIC WORKS FUNDS ASSIGNED FOR CLASS II PROJECTS IN MUNICIPALITIES	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR NEW CLASS II PROJECTS
		Total cost	Public works funds	Regular Federal aid	Mileage	Estimated total cost	Public works funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	Public works funds allotted	Mileage	
	$	$	$	$		$	$	$			$		$
Alabama	2,092,533					283,370.58	283,370.58		31.8	7.7	145,359.80	5.6	1,663,802.62
Arizona	781,794	6,427.92	6,427.92		.6	48,580.21	43,999.66		8.1	1.6	107,565.46	1.7	623,800.96
Arkansas	1,687,084					449,712.15	381,118.60	68,593.55	20.7	11.5	233,226.16	7.6	1,072,739.24
California	3,901,839	61,839.78	55,291.30		2.2	1,797,975.84	1,578,030.15		11.2	22.9	961,170.55	12.8	1,307,347.00
Colorado	1,718,633	128,443.81	128,443.81		3.3	300,312.15	300,312.15		10.8	5.5	312,065.76	5.9	977,811.28
Connecticut	802,407	52,696.86	52,696.86		.5	430,230.83	430,230.83		30.3	6.9	255,987.28	2.3	63,492.03
Delaware	454,772	75,309.50	75,309.50		1.5	149,600.00	149,600.00		3.8	1.1	50,710.00	.8	179,152.50
Florida	1,307,959					637,053.01	429,287.80	207,765.21	26.8	7.2	878,671.20	10.3	
Georgia	2,724,620					363,826.39	363,826.39		18.7	10.3	306,740.42	16.5	2,054,053.19
Idaho	1,121,562	22,291.47	22,291.47		1.7	320,236.37	314,841.97		11.3	5.4	36,803.14	2.0	747,625.42
Illinois	6,877,199	45,749.72	45,749.72		.6	2,751,849.25	2,751,849.25		9.6	26.2	3,151,968.22	32.4	927,631.81
Indiana	4,818,165					24,698.54	24,698.54		4.0	.4	140,870.89	3.0	4,652,595.57
Iowa	2,815,585	253,708.74	242,350.00		8.6	657,911.44	618,150.00		17.1	14.6	705,915.00	17.2	1,249,170.00
Kansas	2,522,401	24,291.11	24,291.11		1.0	1,121,956.62	1,088,896.38		2.8	14.4	1,409,213.51	21.7	
Kentucky	2,029,687	13,307.85	13,307.85		.2	49,231.08	49,231.08		7.5	.7	352,411.28	9.9	1,614,736.79
Louisiana	1,457,148	32,826.75	32,826.75		.1	325,613.74	325,613.74		50.7	6.5	119,476.09	6.4	979,231.42
Maine	842,479	79,296.57	79,296.57		1.6	350,433.41	350,433.41		32.4	8.5	206,951.72	3.3	205,797.30
Maryland	891,132					16,788.76	12,638.76		79.1	.6			878,493.24
Massachusetts	5,007,199	53,896.49	30,896.49	23,000.00	1.5	3,009,497.66	2,995,397.66	14,100.00	13.3	12.2	310,455.80	1.1	1,670,449.05
Michigan	4,457,679	180,700.00	180,700.00		2.3	1,046,470.00	1,044,320.00		7.8	20.4	1,383,046.00	8.0	1,549,613.00
Minnesota	3,410,102	467,206.86	467,206.86		32.7	753,470.90	753,470.90		48.7	30.4	430,801.53	18.1	1,758,622.71
Mississippi	1,744,669					350,871.53	324,704.39	26,167.44	21.9	12.2	116,976.43	7.3	1,302,988.18
Missouri	3,045,077	4,587.13	3,305.88		.3	777,489.27	765,426.15		33.3	8.8	795,002.23	19.1	1,481,342.74
Montana	1,115,962	2,878.39	2,878.39		.1	359,459.22	359,459.22		19.0	9.6	104,507.43	8.1	649,116.96
Nebraska	1,957,240	29,267.12	28,577.83		3.6	896,362.68	896,362.68		28.3	16.2	343,325.63	8.3	688,973.86
Nevada	500,051	50,304.27	50,304.27		1.2								449,746.73
New Hampshire	706,640					318,013.03	318,013.03		12.6	6.9	346,352.92	8.7	42,274.05
New Jersey	3,217,442	70,309.86	70,309.86		.8	1,648,571.00	1,648,571.00		22.9	12.5	630,404.30	6.0	868,156.84
New Mexico	1,448,234	10,526.42	10,526.42		1.0	407,952.45	407,952.45		15.8	7.3	241,332.37	8.2	788,422.76
New York	7,837,865	129,750.00	129,750.00		2.2	4,518,330.00	4,392,045.00		16.4	36.5	2,759,588.00	20.8	556,482.00
North Carolina	2,380,573	48,650.33	48,650.33		3.7	135,891.79	135,891.79		32.6	8.5	264,663.05	12.1	1,931,367.83
North Dakota	1,451,112	2,207.85	2,207.85		1.1	49,955.24	49,955.24		33.6	6.2	303,890.76	11.5	1,095,058.15
Ohio	4,645,378	63,410.00	55,935.00		2.0	1,173,680.00	1,091,180.00		24.5	13.5	1,366,348.43	17.1	3,131,914.57
Oklahoma	2,304,200	18,612.59	18,612.59		.8	306,229.29	306,229.29		9.9	8.0	893,617.17	19.3	1,085,740.95
Oregon	1,526,724	23,731.40	23,731.40		.6	605,684.88	591,369.15	14,315.73	7.0	10.3	489,189.48	12.4	422,433.97
Pennsylvania	5,416,051	68,643.58	68,643.58		2.8	1,108,022.40	1,099,002.28		24.2	21.6	1,522,588.35	23.6	2,725,816.79
Rhode Island	499,677					155,048.79	155,048.79		2.6	2.4	106,304.22	1.8	238,323.99
South Carolina	1,364,791	24,919.48	24,919.48		1.7	211,930.64	211,525.63	405.01	10.0	14.4	222,461.30	7.5	905,884.59
South Dakota	1,502,870	75,816.40	75,816.40		5.2	158,605.22	158,605.22		12.7	5.9	190,209.51	7.2	1,078,238.87
Tennessee	2,123,155	19,992.06	19,992.06		1.1	245,739.64	245,739.64		19.9	4.3	504,342.86	8.3	1,353,080.44
Texas	6,061,006	57,811.09	48,312.46		5.4	1,459,189.34	1,313,809.79		16.9	54.0	1,510,285.81	31.3	3,158,597.94
Utah	771,826	351,502.28	351,425.28		8.8	187,168.55	186,209.55		28.2	4.9	62,132.42	2.0	172,058.75
Vermont	470,628	3,854.07	3,854.07		.6	298,777.26	297,549.64		21.6	8.2	128,245.15	2.9	40,979.14
Virginia	1,854,189	51,612.44	42,851.95	8,760.49	2.0	382,857.16	370,357.16		27.9	8.0	1,080,471.55	14.6	360,508.34
Washington	1,877,571	110,211.77	110,211.77		3.2	501,303.27	496,515.67		12.8	9.8	1,062,218.41	18.0	208,625.15
West Virginia	1,342,270	15,323.43	15,323.43		.4	186,737.74	186,737.74		18.6	4.0	426,277.66	7.8	713,931.17
Wisconsin	2,431,220	151,529.60	151,529.60		4.7	636,105.60	636,105.60		32.6	16.8	260,044.64	6.2	1,383,540.16
Wyoming	1,125,332	53,504.69	53,004.69		1.1	252,799.93	252,799.93		11.5	6.2	357,776.09	7.7	461,751.29
District of Columbia	959,235	295,584.85	295,584.85		2.4	570,729.00	570,729.00		6.0	1.7	92,921.15	.6	
Hawaii													
TOTALS	113,402,967	3,232,534.53	3,163,345.65	31,760.49	115.2	32,792,324.15	31,757,212.88	331,346.94	17.9	533.7	27,660,887.13	485.0	50,801,521.34

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION
AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

CLASS III—PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF JANUARY 31,1934

STATE	PUBLIC WORKS FUNDS ASSIGNED FOR CLASS III PROJECTS ON SECONDARY HIGHWAYS	COMPLETED			UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR NEW CLASS III PROJECTS	STATE
		Total cost	Public works funds	Mileage	Estimated total cost	Public works funds allotted	Percentage completed	Mileage	Public works funds allotted	Mileage		
	$	$	$		$	$			$		$	
Alabama	2,092,533				53,918.15	53,918.15	3.7	.8	85,609.15	12.6	1,953,005.70	Alabama
Arizona	625,435				379,056.78	315,700.00	8.9	31.8	54,830.68	.3	294,904.32	Arizona
Arkansas	1,687,084				293,499.87	293,499.87	3.1	15.0	194,488.38	34.8	1,199,096.35	Arkansas
California	3,901,838				1,581,781.61	1,245,217.35	14.0	109.0	1,080,964.69	32.3	1,635,655.96	California
Colorado	1,718,632	50,000.00	50,000.00	12.2	639,262.42	639,262.42	62.4	111.4	300,354.84	32.2	729,014.74	Colorado
Connecticut	659,180				684,915.58	699,120.00	2.0	14.5				Connecticut
Delaware	454,772								138,758.00	1.8	316,080.00	Delaware
Florida	1,307,958				1,097,261.16	1,097,261.16	16.7	65.0	180,441.97	3.4	90,854.87	Florida
Georgia	2,320,973				102,800.54	102,800.54	11.7	12.5	392,307.88	15.8	1,826,464.58	Georgia
Idaho	1,121,562	54,025.34	49,923.08	6.8	824,240.13	792,218.80	37.6	117.8			279,420.18	Idaho
Illinois	6,262,223	22,161.15	22,161.15	3.5	1,235,769.20	1,235,769.20	12.0	186.7	1,895,287.26	117.8	3,109,005.39	Illinois
Indiana	501,892				165,000.00	165,000.00	10.3	48.1	151,464.91	11.6	185,427.09	Indiana
Iowa	2,212,245	59,388.56	58,100.00	10.0	494,851.23	470,900.00	42.5	45.3	354,000.00	54.7	1,389,245.00	Iowa
Kansas	2,522,401				658,119.38	658,119.38	3.8	71.4	1,864,281.62	113.5		Kansas
Kentucky	1,879,340				1,169,215.17	1,169,215.17	10.4	154.0	664,724.04	69.0	45,400.79	Kentucky
Louisiana	1,457,148				371,567.82	371,567.82	15.3	15.5	263,439.46	17.5	822,140.72	Louisiana
Maine	842,479	564,255.93	560,104.50	68.0	318,148.97	265,305.68	77.2	29.8	8,989.70	.2	8,079.18	Maine
Maryland	891,132				179,884.07	179,884.07	12.8	12.9	271,118.80	21.7	440,129.73	Maryland
Massachusetts	488,185				469,741.41	469,741.41	34.9	15.2			18,443.59	Massachusetts
Michigan	3,184,057				1,831,000.00	1,831,000.00	5.6	142.2	954,750.00	90.5	394,307.00	Michigan
Minnesota	2,131,314	145,774.08	145,774.08	56.9	1,186,066.92	1,105,635.92	21.1	161.9	284,800.02	50.1	615,103.98	Minnesota
Mississippi	1,744,669				435,000.00	435,000.00	34.7	54.6			1,309,669.00	Mississippi
Missouri	3,045,076				1,998,477.63	1,998,477.63	19.5	384.1	812,022.93	98.7	234,575.44	Missouri
Montana	1,859,937	21,033.70	21,033.70	2.3	663,065.04	663,065.04	4.8	71.3	449,847.61	99.1	786,590.65	Montana
Nebraska	1,957,840				1,757,064.92	1,755,202.60	21.6	250.3	81,969.81	7.0	180,068.19	Nebraska
Nevada	1,136,479				852,640.45	852,640.45	23.1	97.0			283,838.55	Nevada
New Hampshire	477,460				494,972.03	453,460.00	23.8	25.1	24,000.00	.5		New Hampshire
New Jersey	63,460				56,550.52	56,550.52	3.5	.5			6,909.48	New Jersey
New Mexico	1,448,234	9,000.00	9,000.00	4.0	1,071,950.00	1,071,950.00	31.3	697.7	63,900.00	73.0	303,384.00	New Mexico
New York	3,662,137	144,300.00	144,300.00	4.6	3,809,913.19	3,378,488.19	14.8	93.1	94,475.00	1.9	44,873.81	New York
North Carolina	2,380,573	136,533.26	136,533.26	16.3	1,023,427.93	1,023,427.93	25.1	89.2	74,984.30	11.3	1,145,687.51	North Carolina
North Dakota	1,451,112								46,035.01	10.4	1,405,076.99	North Dakota
Ohio	3,871,148	71,000.00	71,000.00	30.5	2,424,480.00	2,318,984.90	22.4	242.7	907,810.00	29.1	573,953.10	Ohio
Oklahoma	2,304,199								647,185.02	93.4	1,657,013.98	Oklahoma
Oregon	1,526,724				592,391.68	591,391.68	7.1	20.2	843,733.39	69.1	91,598.93	Oregon
Pennsylvania	7,716,975	32,266.00	32,266.00	4.0	5,949,384.85	5,894,946.40	23.4	581.7	1,056,704.43	89.1	733,058.17	Pennsylvania
Rhode Island	499,677				70,179.89	70,179.89	1.4	6.0	253,906.32	20.1	175,588.79	Rhode Island
South Carolina	1,364,791				1,157,796.30	1,157,796.30	16.0	135.8	65,649.83	3.0	141,344.87	South Carolina
South Dakota	1,502,870	39,421.46	39,421.46	16.1	43,072.35	43,072.35	68.7	14.8	119,808.50	45.9	1,301,167.69	South Dakota
Tennessee	2,123,155				369,461.70	369,461.70	22.5	38.8	664,749.54	67.6	888,943.76	Tennessee
Texas	6,061,006	13,451.11	6,850.00	8.9	4,121,840.85	3,209,592.90	27.2	540.8	1,387,049.54	192.5	1,457,513.56	Texas
Utah	1,048,677	61,543.36	61,543.36	8.0	758,171.26	757,124.24	39.0	136.9	106,733.22	6.0	183,276.18	Utah
Vermont	465,026				327,773.35	309,469.49	18.7	28.8	28,124.48	1.9	127,432.03	Vermont
Virginia	1,854,189	16,000.00	16,000.00	11.7	1,301,621.03	1,260,738.44	26.2	186.8	249,388.95	10.8	328,061.61	Virginia
Washington	1,180,362	36,856.60	36,856.60	11.6	873,623.16	863,623.16	12.5	43.4	115,050.50	10.1	164,831.74	Washington
West Virginia	1,118,559				397,153.15	397,153.15	10.3	23.0	399,486.33	22.2	321,919.52	West Virginia
Wisconsin	2,431,220	26,056.01	26,056.01	.6	1,449,830.75	1,410,815.47	20.6	94.8	313,193.38	25.6	681,155.14	Wisconsin
Wyoming	1,125,332	32,972.04	31,300.00	4.1	576,809.16	565,815.00	37.6	88.7	154,396.65	20.3	373,820.35	Wyoming
District of Columbia	959,234	116,450.00	116,450.00	2.0	681,145.93	658,254.90	14.2	4.4	184,529.10	1.4		District of Columbia
Hawaii	187,106								180,042.06	4.9	7,063.94	Hawaii
TOTALS	94,828,950	1,652,488.60	1,634,673.20	282.1	46,973,236.93	44,687,216.67	20.8	5,230.7	18,527,522.10	1,647.5	29,979,536.03	TOTALS

PUBLICATIONS of the BUREAU OF PUBLIC ROADS

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D.C. As his office is not connected with the Department and as the Department does not sell publications, please send no remittance to the United States Department of Agriculture.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1924. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1927. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1928. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1929. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1932. 10 cents.

DEPARTMENT BULLETINS

No. 136D . . Highway Bonds. 20 cents.

No. 347D . . Methods for the Determination of the Physical Properties of Road-Building Rock. 10 cents.

No. 532D . . The Expansion and Contraction of Concrete and Concrete Roads. 10 cents.

No. 583D . . Reports on Experimental Convict Road Camp, Fulton County, Ga. 25 cents.

No. 660D . . Highway Cost Keeping. 10 cents.

No. 1279D . . Rural Highway Mileage, Income, and Expenditures, 1921 and 1922. 15 cents.

TECHNICAL BULLETINS

No. 55T . . Highway Bridge Surveys. 20 cents.

No. 265T . . Electrical Equipment on Movable Bridges. 35 cents.

MISCELLANEOUS CIRCULARS

No. 62MC . . Standards Governing Plans, Specifications, Contract Forms, and Estimates for Federal-Aid Highway Projects. 5 cents.

No. 93MC . . Direct Production Costs of Broken Stone. 25 cents.

MISCELLANEOUS PUBLICATION

No. 76MP . . The results of Physical Tests of Road-Building Rock. 25 cents.

No. ——— . . Federal Legislation and Regulations Relating to Highway Construction. 10 cents.

REPRINT FROM PUBLIC ROADS

Reports on Subgrade Soil Studies. 40 cents.

Single copies of the following publications may be obtained from the Bureau of Public Roads upon request. They cannot be purchased from the Superintendent of Documents.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

A complete list of the publications of the Bureau of Public Roads, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to the U.S. Bureau of Public Roads, Willard Building, Washington, D.C.

CURRENT STATUS OF U.S. PUBLIC WORKS ROAD CONSTRUCTION
AS PROVIDED IN TITLE II, SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT

SUMMARY OF CLASSES I, II, AND III

AS OF JANUARY 31,1934

STATE	TOTAL APPORTIONMENT OF PUBLIC WORKS FUNDS	COMPLETED				UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION		BALANCE OF PUBLIC WORKS FUNDS AVAILABLE FOR ALL NEW PROJECTS
		Total cost	Public works funds	Regular Federal aid	Mileage	Estimated total cost	Public works funds allotted	Regular Federal aid allotted	Percentage completed	Mileage	Public works funds allotted	Mileage	
	$	$	$	$		$	$	$			$		$
Alabama	8,370,133					4,779,023.49	2,788,396.85	1,990,626.64	26.4	258.8	823,967.57	76.4	4,757,768.58
Arizona	5,211,960	311,966.53	311,966.53		22.2	3,476,998.86	3,026,779.65		24.8	261.4	344,718.27	5.3	1,528,495.55
Arkansas	6,748,335	18,339.52	9,849.52	8,490.00	.6	2,142,809.67	1,694,653.75	447,555.92	26.4	83.4	1,020,648.01	84.4	4,023,183.72
California	15,607,354	153,985.20	129,694.50		4.0	10,942,699.40	8,717,322.47		20.4	359.6	3,114,134.75	89.0	3,646,202.28
Colorado	6,874,530	679,330.81	679,330.81		48.8	2,422,268.08	2,411,687.73		39.0	185.4	908,215.58	50.1	2,875,295.58
Connecticut	2,865,740	52,696.86	52,696.86		.5	2,326,048.13	2,144,473.61	175,778.94	9.4	45.8	565,835.77	8.6	102,733.76
Delaware	1,819,088	208,841.80	208,841.80		16.9	892,415.70	892,415.70		18.4	18.5	189,462.00	2.6	528,368.50
Florida	5,231,834					4,306,979.87	3,318,330.45	988,039.32	27.1	164.8	1,554,760.60	32.0	358,742.95
Georgia	10,091,185					2,225,472.25	2,225,472.25		30.2	118.9	1,822,498.35	109.2	6,043,214.40
Idaho	4,486,249	350,816.30	345,485.12		44.0	2,503,380.61	2,452,460.73		37.5	218.3	183,322.04	15.4	1,504,981.11
Illinois	17,570,770	67,910.87	67,910.87		4.1	4,910,434.48	4,910,434.48		10.3	174.7	5,611,110.53	158.4	6,981,314.12
Indiana	10,037,843					2,164,115.34	2,164,115.34		27.0	116.0	1,416,538.44	46.8	6,457,189.22
Iowa	10,055,660	1,020,135.11	1,004,850.00		48.6	5,100,857.10	4,808,750.00		29.7	269.7	1,552,395.00	94.7	2,689,665.00
Kansas	10,089,604	173,948.41	173,948.41		50.5	4,879,916.41	4,842,895.04		22.0	371.2	5,072,760.55	201.6	
Kentucky	7,517,359	103,886.95	103,886.95		3.1	3,041,677.48	3,041,677.48		23.9	296.8	2,172,645.14	166.8	2,199,149.43
Louisiana	5,828,591	45,452.82	45,452.82		.5	2,723,526.60	2,216,875.60		25.2	59.0	1,167,467.36	54.4	2,398,795.22
Maine	3,369,917	843,552.50	639,401.07		69.6	1,829,903.68	1,741,493.44		41.9	73.8	434,011.58	10.9	555,010.91
Maryland	3,564,527					997,816.61	984,017.86		8.9	28.3	271,118.20	21.7	2,309,390.94
Massachusetts	6,597,100	207,833.37	114,849.13	92,984.24	5.7	4,591,601.53	4,261,841.89	329,759.64	16.5	60.2	423,153.99	1.9	1,797,254.99
Michigan	12,736,227	216,200.00	216,200.00		3.5	5,327,020.00	5,324,870.00		18.9	893.2	4,618,662.00	186.5	2,576,495.00
Minnesota	10,656,569	1,845,260.53	1,845,260.53		346.8	3,758,847.63	3,678,416.61		31.2	458.6	1,210,860.27	209.4	3,922,031.59
Mississippi	6,978,675					3,695,807.94	2,324,200.01	1,332,975.99	16.8	211.8	577,751.84	64.0	4,076,723.15
Missouri	12,180,306	322,760.82	222,812.20		20.4	6,095,614.48	5,768,525.52	25,499.64	33.0	478.1	3,154,007.34	168.1	3,034,960.94
Montana	7,439,748	241,914.17	241,914.17		36.4	4,731,329.66	4,458,450.78	192,878.88	26.8	349.4	1,210,358.50	107.9	1,529,024.55
Nebraska	7,828,961	410,391.09	283,998.37		148.4	6,453,070.85	5,596,975.42	108,538.00	31.9	442.8	982,982.95	72.6	965,004.26
Nevada	4,545,917	322,539.87	322,539.87		61.5	2,319,345.93	2,319,345.93		22.7	228.4			1,904,031.20
New Hampshire	1,909,839					1,358,320.37	1,311,123.34		23.0	41.2	469,473.01	10.8	129,242.65
New Jersey	6,346,039	70,309.86	70,309.86		.8	2,803,677.08	2,803,677.08		17.2	32.3	1,476,322.29	16.3	1,995,729.77
New Mexico	5,792,935	1,092,305.73	1,092,305.73		144.0	2,790,965.68	2,790,965.68		15.5	799.3	731,496.48	125.6	1,178,167.11
New York	22,330,101	391,150.00	391,150.00		10.6	17,526,093.19	15,995,708.19	315,000.00	20.1	331.4	4,712,293.00	52.3	1,230,949.81
North Carolina	9,522,293	629,883.69	407,533.67	222,350.02	55.1	2,448,658.52	2,119,000.82	329,657.70	29.5	246.8	1,918,075.06	242.1	5,077,683.45
North Dakota	5,804,448	502,968.94	502,965.43		250.8	911,033.06	911,033.06		12.2	236.8	1,515,220.58	377.5	2,875,228.93
Ohio	15,484,592	347,780.00	340,305.00		37.3	9,284,365.00	8,978,479.90		30.1	403.7	3,157,533.43	67.6	3,008,273.67
Oklahoma	9,216,798	141,314.93	141,314.93		5.9	3,485,728.59	3,485,728.59		33.9	203.8	2,375,791.43	191.3	3,213,963.05
Oregon	6,106,896	368,858.06	340,964.56		41.0	3,401,587.82	3,281,734.03	28,932.26	17.2	132.0	1,797,628.97	119.4	686,568.44
Pennsylvania	18,891,004	113,700.68	113,700.68		7.0	11,042,432.39	10,978,973.82		19.2	700.5	4,025,456.92	139.3	3,772,872.58
Rhode Island	1,998,708	18,830.63	18,830.63		.5	1,194,381.89	1,194,381.89		21.4	28.4	370,680.91	21.9	414,814.57
South Carolina	5,459,165	26,660.17	26,660.17		1.7	3,255,946.44	3,252,811.81	3,134.63	21.7	334.6	570,953.77	33.0	1,608,739.25
South Dakota	6,011,479	986,251.27	980,334.78	5,916.49	166.3	1,303,145.05	1,271,120.76	32,024.29	9.2	197.9	776,584.16	103.3	2,983,439.30
Tennessee	8,492,619	151,879.70	92,583.06	59,296.64	6.2	3,187,107.38	2,670,386.64	516,720.74	22.6	141.6	2,626,998.12	124.6	3,102,651.18
Texas	24,244,024	446,777.45	356,395.41		111.8	12,732,400.06	10,596,226.04		24.0	1,211.1	5,348,933.58	493.7	7,942,468.97
Utah	4,194,708	1,282,715.85	1,282,638.95		118.3	1,977,559.68	1,975,158.76		30.9	222.7	468,925.40	20.1	467,984.99
Vermont	1,867,573	51,837.88	51,837.88		6.8	1,361,902.46	1,314,217.73		25.3	71.7	156,369.63	4.8	345,147.76
Virginia	7,416,757	218,408.33	192,464.97	25,943.36	23.9	3,270,497.59	3,216,702.69	412.31	29.0	250.9	2,895,077.05	85.5	1,112,512.29
Washington	6,115,867	349,714.25	349,714.25		28.5	3,479,999.85	3,461,855.43	3,356.82	16.1	128.6	1,547,876.11	43.0	756,421.21
West Virginia	4,474,234	159,357.43	159,357.43		5.3	2,106,274.77	2,106,274.77		32.9	91.5	1,087,290.90	32.8	1,121,310.90
Wisconsin	9,724,881	476,062.86	465,760.03	1,190.00	21.0	4,588,611.66	4,528,096.38	21,500.00	31.6	212.7	1,007,584.70	69.3	3,723,439.89
Wyoming	4,501,327	662,497.61	572,604.69	60,000.00	113.4	2,359,163.89	2,260,467.93	18,000.00	24.3	403.6	616,555.35	67.0	1,051,699.03
District of Columbia	1,918,469	412,034.85	412,034.85		4.4	1,251,874.93	1,228,983.90		10.4	6.1	277,450.25	2.0	
Hawaii	1,871,062	25,988.65	12,994.33	12,994.32	.9	1,328,218.44	1,096,391.33	191,827.36	4.4	27.9	461,479.56	8.9	300,196.78
TOTALS	394,000,000	16,325,052.35	15,395,650.72	489,165.07	2,097.6	197,088,327.57	180,944,379.16	7,042,219.08	23.8	12,084.0	80,795,437.59	4,490.8	116,864,532.53